

THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Supporting Operators with their Daily Tasks in Complex Production  
Environments - a Perspective on ICT Tools

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Supporting Operators with their Daily Tasks in Complex Production Environments  
- a Perspective on ICT Tools  
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Cover:

The cover illustration is depicting some possible applications of ICT (Information and communication technology) tools to support operators in industry.

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# Abstract

To achieve a sustainable competitive business all resources needs to be utilized. Within a manufacturing company the shop-floor operators are one of those resources. The shop-floor operators has been called “*A key to future competitiveness and effectiveness*”. To facilitate high operator performance the equipment required to support their tasks ought to be provided. Information and communication technology (ICT) could provide cognitive support and through technological advancements the possibilities of communication and information sharing seems endless. Authors suggests that ICT tools supporting the operators are needed.

The aim of this thesis is to contribute to a better understanding of what challenges faced by operators can be aided by ICT tools and how to evaluate this support.

Operators frequently faces various challenges during a work day. This thesis identifies and discusses ten challenges relating to information and communication. These challenges can be approached and supported in several ways. In the thesis it is discussed how mobile and digital ICT tools can support operators with identified challenges. Evaluating the outcome of any change is important and so is evaluating changes and impact from ICT tools. In this thesis examples of performance measures are presented and a few aspects to consider when selecting them are discussed.

A framework “Operator-support tool” was suggested to aid in the endeavours of identifying challenges faced by operators and selecting performance measures (in addition to use in the design phase). This framework was beneficial in maintaining a wide perspective and ensuring consideration of the three aspects of operators, their tasks and support tools.

**Keywords:** operator, ICT tools, cognitive support, complex production environment



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# Appended Publications

N.b. The author has changed her surname from Karlsson to Tarrar.

## Publication A:

**Karlsson, M.**, Mattsson, S., Fasth-Berglund, Å., & Stahre, J. (2013 ). “Could the use of ICT tools be the way to increase competitiveness in Swedish industry?”, *12th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design, and Evaluation of Human-Machine Systems, Las Vegas Nevada, USA*.

## Work distribution

**Tarrar, M.** conducted the multiple-case study with Mattsson, S., performed data analysis and wrote the main sections of the paper. **Tarrar, M.** presented the paper at the conference.

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## Publication B:

Mattsson, S., **Karlsson, M.**, Fast-Berglund, Å., & Hansson, I. (2014). ”Managing Production Complexity by Empowering Workers: Six Cases”, *47th CIRP Conference on Manufacturing Systems, Canada*.

## Work distribution

**Tarrar, M.** and Mattsson, S. carried out the data analysis and wrote the paper. **Tarrar, M.** with either of the co-authors conducted the multiple-case study. **Tarrar, M.** presented the paper at the conference.

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## Publication C:

Åkerman, M., Fast-Berglund, Å., **Karlsson, M.**, & Stahre, J. (2016). ”Introducing customized ICT for operators in manufacturing”, *Procedia CIRP*, 41, 490-495.

## Work distribution

**Tarrar, M.** and Åkerman, M. conducted the case study and carried out data analysis. **Tarrar, M.** wrote some of the paper.

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## Publication D:

Mattsson, S., **Tarrar, M.**, & Fast-Berglund, Å. (2016) “Perceived Production Complexity – understanding more than parts of a system”, *International Journal of Production Research*

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**Tarrar, M.** and Mattsson, S. gathered and analysed the data. **Tarrar, M.** wrote some of the paper.

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# Additional Publications

1. Mattsson, S., Fasth, Å., Stahre, J., Dencker, K., Gullander, P., Davidsson, A. & **Karlsson, M.** (2013). "Validation of the complexity index method at three manufacturing companies", *Proceedings for the IEEE International Symposium on Assembly and Manufacturing, ISAM 2013*
2. Mattsson, S., **Karlsson, M.**, Gullander, P., van Landeghem, H., Zeltzer, L., Limère, V., Aghezzaf, El-H., Fasth, Å. & Stahre, J. (2014). "Comparing quantifiable methods to measure complexity in assembly", *International Journal of Manufacturing Research*
3. Fast-Berglund, Å., Bligård, L-O., Åkerman, M. & **Karlsson, M.** (2014). "Using the TRL methodology to design supporting ICT-tools for production operator", *Procedia CIRP. 47th CIRP Conference on Manufacturing Systems, CMS 2014*
4. Fast-Berglund, Å., Åkerman, M., **Karlsson, M.**, Garrido Hernández, V. & Stahre, J. (2014). "Cognitive automation strategies: Improving use-efficiency of carrier and content of information", *Procedia CIRP. 47th CIRP Conference on Manufacturing Systems, CMS 2014*
5. **Karlsson, M.**, Gustafsson, A., Grane, C. & Stahre, J. (2014). "ICT usage and benefits in Swedish manufacturing and process companies", *The 6th Swedish Production Symposium*.
6. Åkerman, M., **Karlsson, M.** & Bligård, L-O. (2014). "Refining the needs: an exploratory study through usability testing", *The 6th Swedish Production Symposium*.
7. Saène, F., **Karlsson, M.** & Johansson, B. (2014). "Usage of Strategies and ICT tools in automotive industries during recovery tasks - A literature review", *The 6th Swedish Production Symposium*.
8. Li, D., Landström, A., Mattsson, S. & **Karlsson, M.** (2014). "How changes in cognitive automation can affect operator performance and productivity", *The 6th Swedish Production Symposium*.
9. Åkerman, M., **Karlsson, M.**, Fast-Berglund, Å. & Stahre, J. (2015). "Information for operational tasks: five cases in Swedish production", *The International Conference on Flexible Automation and Intelligent Manufacturing (FAIM)*
10. Falck, A-C., Andersson, L., Mattsson, S., **Karlsson, M.**, Rosenqvist, M. & Söderberg, R. (2015). "A comparison of two methods for assembly complexity- What are they good for?" *NES, Nordic Ergonomics Society, 47th Annual Conference*
11. **Tarrar, M.**, Svensson Harari, N. & Mattsson, S. (2016). "Using the CompleXity Index to discuss improvements at work: a case study in an automotive company", *The 7th Swedish Production Symposium*
12. Falck, A-C., **Tarrar, M.**, Mattsson, S., Rosenqvist, M., Söderberg, R. & Andersson, A. (2017). "Assessment of assembly complexity: a theoretical and empirical comparison of two methods", *International Journal of Production Research*

# Table of Contents

1	Introduction .....	1
1.1	Managing Operators as a Resource .....	1
1.2	Future Work Tasks and Operators .....	1
1.3	Operator Support Tools.....	2
1.4	Aim and Research Questions .....	3
1.5	Delimitations .....	3
2	Frame of Reference .....	5
2.1	Operators in Manufacturing Companies .....	5
2.2	Complexity in manufacturing .....	6
2.2.1	Assessing and managing complexity .....	6
2.3	ICT tools to support operators.....	7
2.3.1	Examples of ICT tools supporting operators.....	7
2.3.2	Evaluating impacts of ICT tools .....	8
2.3.3	Approaches to improvements of ICT tools supporting operators.....	9
2.4	A few aspects of design theory.....	9
2.5	Purpose and Scope of Research.....	13
3	Research Methodology .....	17
3.1	Inductive Research Procedure.....	17
3.2	Research design .....	18
3.2.1	Case study.....	19
3.2.2	Survey .....	20
3.3	Data collection.....	20
3.3.1	Semi-Structured Interviews .....	20
3.3.2	Questionnaire .....	20
3.3.3	Direct observation .....	21
3.3.4	Production data and log data .....	21
3.4	Analysis.....	21
3.4.1	Content analysis and Grounded Theory.....	21
3.4.2	Action space .....	21
3.4.3	Carrier and content .....	22
3.4.4	Statistical analysis.....	22
3.5	Introducing the appended publications and contributing projects.....	22
3.5.1	Data collection and analysis within the Operator of the Future project .....	24
3.6	Ethics .....	26
4	Summary of Appended Publications .....	29
4.1	Summary publication A - Could the use of ICT tools be the way to increase	



competitiveness in Swedish industry? .....	29
4.2 Summary publication B - Managing production complexity by empowering workers: six cases .....	30
4.3 Summary publication C - Introducing customized ICT for operators in manufacturing.....	31
4.4 Summary publication D - Perceived production complexity - understanding more than parts of a system .....	32
5 Synthesis of Answers to Research Questions .....	33
5.1 Results RQ 1 - What are the challenges operators face in their daily tasks, in complex production environments? .....	33
5.2 Results RQ2 - How can operators in complex production environments be supported in these challenges through digital and mobile ICT tools? .....	36
5.3 Results RQ3 - What performance measures could be used to evaluate effects of digital and mobile ICT tools supporting operators in production environments? .....	37
6 Discussion .....	41
6.1 Complex production environment .....	41
6.2 RQ1 What are the challenges operators face in their daily tasks, in complex production environments? .....	41
6.2.1 The challenges and their identification in research articles .....	42
6.2.2 Challenges their occurrence and influencers .....	43
6.3 RQ2 How can operators in complex production environments be supported in these challenges through digital and mobile ICT tools? .....	44
6.4 RQ3 What performance measures could be used to evaluate effects of digital and mobile ICT tools supporting operators in production environments? .....	45
6.5 Summarising the discussion of ICT tools supporting operators .....	48
6.5.1 Approaching improvements to ICT tools supporting operators.....	49
6.6 Validity and Transferability .....	50
6.7 Future work .....	52
6.8 Contribution to academia and industry .....	52
7 Conclusion .....	55
References .....	59

# List of Figures

Figure 1 The human-centred design pyramid. Redrawn from Giacomini (2014).....	10
Figure 2 Operator-support tool framework for studying operators and support tools using a systems view. Adapted and extended from (Marianne Karlsson, 1996).....	12
Figure 3 Framing of research question 1 shaded area and double-headed arrow. ....	14
Figure 4 Framing of research questions 2 and 3, marked with an arrow and a circle respectively.....	15
Figure 5 The inductive research procedure followed.....	17
Figure 6 The research design and methods used for data collection and analysis. ....	19
Figure 7 Details of research procedure with contributing publications, research projects and case studies. ....	23
Figure 8 The operators' action space, based on Role Allotment.....	31
Figure 9 Areas suggested in the appended publications for evaluating the impact of digital and mobile ICT tools which support operators. ....	39
Figure 10 Operator-support tool framework. ....	49

# List of Tables

Table 1 Role Allotment in production systems; the operators' action space. ....	6
Table 2 The technology change approach matrix, possible combinations of technology push or pull and incremental versus radical improvements. ....	9
Table 3 Summary of methods used within each publication. ....	23
Table 4 Summary of characteristics, methods and participants within the case studies. ....	25
Table 5 Contribution of the appended publications to answering each research question.....	33
Table 6 Challenges and occurrence in assembly and machine/process supervision work.....	35
Table 7 Challenges and influence from operator's level of expertise and distance involved..	36
Table 8 Challenges supported through either mobile and digital ICT tools or independently of information carrier.....	37
Table 9 Occurrence of challenges in different types of manufacturing work. Additions from the literature are marked.....	44
Table 10 Influence of operators' level of experience and proximity on challenges. Additions from the literature are marked. ....	44
Table 11 Researched quadrant of the change approach matrix.....	50
Table 12 Possible use of thesis results. ....	53

# List of Abbreviations

AR – Augmented Reality  
CXI – CompleXity Index  
ICT – Information and Communication Technology  
IT – Information Technology  
PI – Performance Indicator  
ROI – Return on investment  
PPC – perceived production complexity  
VR – Virtual Reality

# List of Definitions

**Mobile and digital ICT tool** – A portable physical unit conveying information and communication in a digital format.

**Performance measure** – Within this thesis performance measure is used not as a specific measurement such as cycle time (time to process a product within one machine) rather it is used to indicate areas to be measured such as social sustainability and product quality (possible to measure in a number of ways both quantitative and qualitative).

**Support tool** – a tool providing support for the operator(s) to handle the work tasks.



# 1

## Introduction

*This chapter introduces the topic of the thesis and the aim and research questions that were addressed in order to achieve it. The chapter ends with a section on delimitations.*

### 1.1 Managing Operators as a Resource

To achieve a sustainable business, companies need to utilise and manage all their resources well. One such resource is the workers at all levels in a company, known as the “human resources”. These resources are often essential to achieving a company’s goals (Buller & Mcevoy, 2012; Hatch & Dyer, 2004). Within manufacturing companies, employees working on the shop-floor with, or close to, the product and value-creation process are known as operators. Similarly, shop-floor operators have been called “*a key to future competitiveness and effectiveness*” (Holm et al., 2016).

For human resources to do a good job, they need to be supported by the right equipment. This could mean anything from ladders to headsets. Equipment needs to be differentiated according to (and right for) the intended tasks. For example, office worker might have little use for a screwdriver, but a telephone or computer might be useful. The possible equipment changes as technology develops; so do the requirements of equipment deemed necessary and productive. For instance, typewriters and archives developed into computers and databases which are now the norm. Operators working in manufacturing are no exception; they are supported by machinery, amongst other things.

### 1.2 Future Work Tasks and Operators

The work of operators has not been static. Rather, it changes over time and has developed from production by craftsman and via various industrial revolutions to the forms of work we see today. It is worth mentioning that new technologies have not always contributed to the de-skilling of workers, but have placed greater cognitive demands on them (Karuppan & Keps, 2006).

Innovation and technological development are ongoing processes, so operators’ tasks will continue to evolve. In a workshop attended by 25 representatives of Swedish industry, the prediction was that future operators will gain more responsibility and expanded work tasks comprising further analysis, problem-solving and interpretations of what is happening (Berlin

et al., 2012; Grane et al., 2012). Similar results were found by Gorecky et al. (2014). This is already a reality in several companies.

The population of many countries (including Sweden) is aging. Thus, in the future there will be fewer people available to hire and fewer people available to carry out the work we have today (Bloom et al., 2015). This could lead to difficulty hiring staff with sufficient knowledge and experience. Among students at Swedish technical high school, the view of the operator work was quite positive (Holm et al., 2016). However, to attract these people the working environment and salary must also be good (Holm et al., 2016). Young people (prospective future operators) have expressed a desire for operator work to include creative tasks which require continuous learning and development (Wikberg Nilsson & Fältholm, 2011).

### 1.3 Operator Support Tools

Increased automation is a possible enabler of changes in the operator's role and work tasks. Although this has been the dream for many years (Merchant, 1961) most manufacturing companies have not achieved complete automation and thus need operators within production. Automation can complement operators and other employees in routine tasks, allowing them more time for problem-solving and creative tasks (Autor, 2015). Dividing tasks between man and machine is no simple matter and requires further investigation beyond general statements on attributes and individual tasks (Chapanis, 1965). Automation may describe technology that facilitates human performance and thus includes physical as well as cognitive support (Fasth, 2012). Examples of physical automation might be pneumatic screwdrivers and robots. Cognitive automation includes such things as instructions, pick-by-light and other aids making it mentally easier to perform tasks (Claeys et al., 2015). Thus, information and communication aids could also be related to cognitive automation.

In the last decade, information and communication technology (ICT) has undergone a massive transformation through such technologies as smartphones. These technologies, in combination with social media, have forever changed our view of communication and information-sharing. The possibilities seems endless.

As stated earlier, operators (human resources) need equipment to handle their work, with what is deemed necessary also depending on technological advancements. However, do operators face obstacles or challenges which necessitate support from new technology? It has been said that technical progress solves some problems but also creates new ones (Liu & Li, 2012). As stated by Martensson and Stahre (1992), information technology can add complexity for operators: *“new developments in information technology will forever change advanced manufacturing towards a higher level of abstraction and complexity”*.

To handle the challenges of changing tasks, uncertainties and increased complexity, some authors have suggested that operators actually need support from new technology (Van Rhijn & Bosch, 2017). Unforeseen events, a changing environment and a rich flow of information make decision-making support necessary if operators are to make the right decisions, set priorities, plan their tasks and thus maintain a high level of production output (Holm et al., 2016). It has also been suggested that novice operators need support so as to quickly acquire skills and perform high quality work (Morioka & Sakakibara, 2010). Thus, some issues seem to necessitate ICT support for operators.

It is important to study how operators should be provided with information and communication support and for which challenges or tasks. Of equal importance is studying the outcomes of operators being provided with these tools. Several researchers have conducted studies of support tools for operators. However, it is not always clear what challenges have been addressed and how the studies have been evaluated as successful or not.

## 1.4 Aim and Research Questions

The aim of this licentiate thesis is *to contribute to a better understanding of what challenges faced by operators can be aided by ICT tools and how to evaluate this support*. Three research questions have been formulated to achieve this aim.

RQ 1) What are the challenges operators face in their daily tasks, in complex production environments?

The focus of this research question is the challenges operators face in relation to information and communication. Challenges in this thesis would mean any areas in which operators, managers or the researcher experienced difficulties or inefficiencies.

RQ 2) How can operators in complex production environments be supported in these challenges through digital and mobile ICT tools?

This question deals with what kind of support digital and mobile ICT tools would be able to provide and which of the identified challenges could be supported by using these ICT tools.

RQ 3) What performance measures could be used to evaluate effects of digital and mobile ICT tools supporting operators in production environments?

The aim of this research question is to provide some diverse examples of performance measures which can be used to evaluate the support gained from digital and mobile ICT tools. Thus, measures of different natures will be considered.

## 1.5 Delimitations

The areas covered by this thesis are those stated in the previous section. To clarify further, a few delimitations will be stated explicitly here. The challenges faced by operators (and any support and evaluation) has been studied in manufacturing companies, with examples from both process and discrete manufacturing. The operators were those working close to the value-adding process, whose responsibility was mainly assembly or machine supervision tasks, (see Publication B).

A range of factors are very important in achieving efficient and effective usage of ICT tools. Although relevant, factors such as those listed below are not considered within this thesis:

- Which ICT tools might be used.
- Acceptance and adoption of technology.
- Backend systems.
- Knowledge management.
- User interaction and experience.
- Manufacturing strategy.
- Devising of instructions (types, content etc.).
- Organisational theory.

Performance measures and indicators can be used to evaluate the impact of ICT tools. Key performance indicators are often used to evaluate a business, the term “performance indicators” is broader and may include indicators not necessarily of key importance to the business. The distinction between “performance indicators” and “performance measures” is not entirely clear in the literature, although, some use “performance measures” to signify a broader scope and “performance indicators” in regard to specific variables (Parida et al., 2015). Despite the lack of a common definition (Larsson, 2017), the phrase “performance measure” is applied within this thesis to indicate a broad scope.

For further scoping and a description of areas considered for each question see section 2.5.





# 2

## Frame of Reference

*This chapter introduces past and present research within a few research areas of importance to the topic of this thesis.*

### 2.1 Operators in Manufacturing Companies

A manufacturing company is a company producing at least one type of product. The product is processed and transformed in the production facility where various combinations of basic operations form the product: division, combination, separation, shaping or adoption of properties (Jonsson & Mattsson, 2009). An example of a combination operation is assembly. Within assembly, parts or components are put together to form a component or finished product (Mosier & Janaro, 1990). Distinctions between manufacturing types can be made based on the products and the way they are produced, two general divisions are: discrete and continuous, meaning process industries (Noroozi & Wikner, 2017). Discrete manufacturing is driven by discrete events occurring in time (Leung & Suri, 1990).

The operators' specific tasks will vary between industries, companies and even different departments or production lines within a company. There might also be distinctions based on responsibilities. One way to describe operators' work and the action space an operator possesses is through the 17 tasks in Role Allotment, (Fast-Berglund & Stahre, 2013) see Table 1. These have been decomposed from Sheridan's five operator roles (Sheridan, 1992), marked with grey in Table 1. The operators' level of experience may influence the action space. Levels of expertise can be divided into expert, experienced and novice.

Table 1 Role Allotment in production systems; the operators' action space.

Plan	Teach	Monitor/ perform	Intervene	Learn
Process planning and production engineering	Programming for a new product	Manual assembling	Disturbance handling	Continuous improvement
Long time planning (>2 weeks)	Material handling	Monitoring machines	Lack of material	Learning new working tasks
Short time planning (1-2 weeks)	Order handling	Maintenance	Small disturbances	Teach new operators
	Set-up		Large disturbances	
			Quality check of product and/or system	

## 2.2 Complexity in manufacturing

To manage production and provide support for a company's production goals, operators need to do high quality work, keep on schedule and generally perform well. Complexity has been seen to have a negative impact on these aspects (Falck & Rosenqvist, 2012; Falck et al., 2017a; Perona & Miragliotta, 2004; Urbanic & Elmaraghy, 2006). Complexity in a system may be described as something which is “*difficult to understand, describe, predict or control*” (Sivadasan et al., 2006) and, depending on how the system is composed, the level of difficulty in predicting its properties (Weaver, 1948). This definition of “complexity” resembles the Latin etymology of the word and the Oxford English Dictionary, as reported in (Vogel & Lasch, 2016).

Operators within manufacturing must often deal with a number of product variants; an unsurprising fact, given the strategy of mass customisation (Coletti & Aichner, 2011) and the large number of variants of many products (cars, machine tools and catheters for example). Product variants have been identified as a cause of complexity (Hu et al., 2008; Orfi et al., 2011). Operators are also affected by various unexpected events in their immediate environment, such as machine or tool failures, changes in instructions or production plans and a fluctuating number of available operators. Operators must manage these uncertainties in their environment and the structure of the plant, which also affects complexity (Calinescu et al., 1998). To do their work, operators must understand, and know how to react to, flows of information (Calinescu et al., 1998) and materials (Sivadasan et al., 2006). These will be affected by such things as the number of product variants and structure of the plant. Operators often need to single out relevant and important details from a constant flow of information.

### 2.2.1 Assessing and managing complexity

A first step in developing a clear strategy to manage complexity in a company is to identify, analyse and understand the complexity drivers (Vogel & Lasch, 2016). Complexity related to production can be assessed early on (product design for example) as well as in later stages (during production). Falck et al. (2017b) developed a method involving 16 criteria to measure basic complexity in design phases. Predictive complexity assessment has also been approached through predetermined motion time systems (PTMS) (Alkan et al., 2016).

Assessing complexity during production has been tackled by several authors using objective data (Mattsson et al., 2014). Zhu et al. (2008) studied operator choice complexity, as did Busogi

et al. (2017), factoring in the mix and similarities of options. Zeltzer et al. (2013) developed the CXC (complexity calculator) and used it to characterize manual operator workstations.

It has been suggested that the complexity perceived by operators is caused by basic complexity in the system and task (Guimaraes et al., 1999). Later, it was argued that perceived complexity originates not only with reflections of objective complexity but from subjective factors as well (Li & Wieringa, 2000). One way of measuring perceived production complexity (PPC) is a method called the CompleXity Index (CXI) (Mattsson, 2013). The CXI method measures complexity from an operator's perspective by consulting them; something which other methods did not do (Mattsson et al., 2014). A CXI index is generated for each station by using a questionnaire.

## 2.3 ICT tools to support operators

As stated in the introduction, development in the field of information and communication transfer has been massive in recent years with more to come. "Cognitive expert advisor" and "conversational interfaces" are examples of technologies mentioned in the Gartner Hype Cycle for Emerging Technologies 2017 (Panetta, 2017). There are also other technologies being developed and finding broader areas of application, such as augmented and virtual reality (AR and VR). Some ICT tools have started to find their way into factories. Smartphones, for example, are widely used among managers. However, this sort of equipment has not been as widespread among shop-floor operators in Sweden (Malin Karlsson et al., 2014).

Massive research efforts are currently underway, relating to the use of technology in production plants in efforts such as Industry 4.0 and Smart Factories (Strozzi et al., 2017). Alongside these endeavours to apply technology generally in factories, efforts are also being made to support operators with ICT, including AR (Syberfeldt et al., 2016). Romero et al. (2016) present a high-level, technologically-focused discussion on how operators can be supported cognitively and physically in Industry 4.0. A successful support system should adapt to workplace conditions and users' level of knowledge, collecting and reusing users' knowledge (Holm et al., 2017).

An updated ICT tool could mean changes to both information carrier and content. The information carrier relates to what type of tool the carrier is, such as paper, telephone or computer. The information content deals with what to present; the actual information or data plus the mode. This might entail an image or text (Fässberg et al., 2012).

### 2.3.1 Examples of ICT tools supporting operators

Niedersteiner et al. (2015) developed a smart workbench to aid operators in assembling a limited number of product variants, with the aim of increasing quality. They used AR and tested this functionality in short experiments, using hand-tracking sensors to show instructions and detect and correct operator errors. Fast-Berglund et al. (2014) provided operators with video instructions to support them in carrying out and learning tasks.

Wearable computers were developed for maintenance staff in a process industry (Aleksy & Rissanen, 2014). From interviews, 39 possible use cases were identified of which two were described. In the first case AR, positioning and cameras guided staff to the right location, recorded staff entering and exiting specific areas and enabled a task to be marked as completed. In the second scenario, a safety suit was constructed including sensors measuring parameters in the environment and on the wearer. The wearer and others could then be alerted to any emergency. Communication was also enabled.

Aiding operators with maintenance was also addressed by Rauh et al. (2015). Novice operators were reportedly unsure of which tasks to perform and how. Completed tasks were

also meant to be reported in two steps; first paper, then computer. Smart glasses and tablets were used in an experiment to address these issues.

Training new assembly operators to do their job correctly was considered as having improvement potential due to a lack of standardisation and the necessary presence of a trainer (Morkos et al., 2012). An AR tool was suggested for training operators. However, it was not implemented due to cost, theft risk and bandwidth limitations.

Providing adaptive instructions through AR and expert systems was suggested and tested in an experiment by Holm et al. (2017). This was to reduce the time distinction between expert and novice operators. The content of the instructions was customised dynamically and was believed to facilitate the learning process. Differences in work procedure between expert and novice operators were also identified through activity analysis by Hoarau et al. (2014). The differentiation of information from machines to managers and operators based on roles has also been addressed (Friedemann et al., 2016).

Fässberg (2012) addressed a question of how to support operators (limited to semi-automated assembly systems), by providing examples of ICT tools that could be used, iPods being one example. Furthermore, it was proposed to address the low usage of existing cognitive support using individualised information and attention triggers. A similar research question was addressed by Åkerman (2016), giving examples of operators using ICT tools. He states that operators can use ICT tools, either to share information or for cognitive automation.

### 2.3.2 Evaluating impacts of ICT tools

Evaluation of ICT tools can and has been addressed at different abstraction levels; from Evaluation of ICT tools can and has been addressed at different levels of abstraction, from assessing the tool itself to considering the performance of the whole manufacturing company. DeLone and McLean developed an information systems success model, incorporating both high and low levels of abstraction: quality of information and system, use, user satisfaction, individual impact and organisational impact (DeLone & Mclean, 1992). McGill et al. (2003) tested the model and found correlations for several of the relations. However, it was not possible to associate the user ratings for individual impact with organisational impact (measured as company performance). Stratopoulos and Dehning (2000) stressed two areas in need of consideration when evaluating IT and financial performance: 1) time is needed before investment has any impact at a high level of abstraction (such as organisational level) and 2) it was found that several companies were not implementing their projects effectively. Thus, evaluations at higher levels of abstraction require a longer time horizon or study than those at lower levels.

Evaluations of users and their work performance have been suggested. Dünser et al. (2008) identified user performance and collaboration as two indicators evaluated in AR studies. Furthermore, time and quality were identified as important (Holm et al., 2017; Morkos et al., 2012).

Evaluations of the tool itself and its usefulness have appeared in several studies. The functionality of the support tool itself was used for evaluation (Niedersteiner et al., 2015). Communication capabilities were suggested (Morkos et al., 2012). Usability is another measure suggested at this level (Aleksy et al., 2009; Dünser et al., 2008; Holm et al., 2017; Niedersteiner et al., 2015). Users' perception of the supporting ICT tool has also been addressed (Dünser et al., 2008; Fast-Berglund et al., 2014). General remarks have also been made regarding cost-effectiveness, reliability (Aleksy & Rissanen, 2014) and return on investment (ROI) (Aleksy & Rissanen, 2014; Morkos et al., 2012).

An evaluation of the impact of ICT tools is not always carried out on operational and functioning systems. Lee and Lastra (2013) assessed a proposed support tool, enhanced with context awareness, by comparing the (potential) characteristics of the information system with and without implementation.

### 2.3.3 Approaches to improvements of ICT tools supporting operators

Improvements of ICT tools supporting operators (and the production system) relate to the field of innovation. Innovations can be made for products, technologies or production systems and similar terminology can be used regardless of the field of innovation.

There are two general ways in which improvements of a production system (and likewise information and communication support to operators) can be classified: 1) incremental, also known as minor and evolutionary and 2) radical, major and transformative (Javadi et al., 2012; Sim, 2001). Thus, the changes are either stepwise, incremental in nature, or a leap forward, a radical change. These terms are often used when discussing innovations (Lewrick et al., 2012). Radical changes require greater investment in pre-studies, time and execution, whilst the effort involved in incremental improvements would be smaller (Rothwell, 1994). A radical change would start by identifying future best practice, whereas incremental change starts with the current situation and what to improve (first).

Relating to this, there are two common start points when considering investments and innovation in, say, technology and operator support tools. These could be referred to as “technology push” and “technology pull” (Rothwell, 1994). Technologies themselves and possible areas of application can be studied. There are several examples dealing with support provided to operators and this would be considered a push approach. Within the pull approach, an innovation is initiated by issues, challenges or needs and should result in the development of technology or products supporting those needs (Norman & Verganti, 2014).

Incremental or radical improvements and technology push and pull could be combined into four different tactics, see Table 2. These tactics could be used when considering how to proceed with ICT tools supporting operators.

*Table 2 The technology change approach matrix, possible combinations of technology push or pull and incremental versus radical improvements.*

	<b>Technology Pull</b>	<b>Technology Push</b>
<b>Incremental changes</b>		
<b>Radical changes</b>		

## 2.4 A few aspects of design theory

In short, the research presented in this thesis relates to operators, their challenges and ICT support tools. These could be translated into users, needs and artefacts; terms commonly used within design theory. A given product or technology should fulfil the needs deduced from goals, tasks, problems and opportunities (Hevner et al., 2004). So, there is indeed a close connection between the research presented in this thesis and design research.

According to Peffers et al. (2007), the process of design science comprises six steps: 1) problem identification and motivation, 2) definition of the objectives for a solution, 3) design and development, 4) demonstration, 5) evaluation, and 6) communication. These steps may be approached differently. Three design paradigms are identified by Giacomini (2014) of which

two might be most relevant to the design of support tools for operators. These are technology-driven design and human-centred design; akin to technology push and pull.

Working with complex systems, as production facilities often are, it is important to remember that the different parts or sub-systems, such as operators, do not exist and function in isolation. Rather, different sub-systems interact to form a whole working towards a goal; ideas consistent with General Systems Theory (Skyttner, 2005). Comparable to systems theory, Archer stated that the study of use should include *the user, the artefact* and *the task* within a *use environment* as reported in (Marianne Karlsson, 1996). Consistent with a systems perspective, the use situation as a whole should be studied before recommendations are made. With these aspects as a background and building on activity theory, Marianne Karlsson (1996) proposed a framework for studying the relationship between user and artefact. Her framework consists of four interacting dimensions, each described with a three-level hierarchy and existing in the environment (local and general conditions);

- *Goal/consequence* – motive/need, goal, fit/misfits,
- *Activity* – activity, action, operation,
- *User* – individual/collective, individual/user, physical and mental properties,
- *Artefact* – technical system, artefact, properties of artefact,

Several other models have been suggested to assist with design research. For example, Giacomini (2014) presents a design pyramid consisting of five questions (Figure 1) to be used by the designer within human-centred design. These questions about the relationship the artefact either creates or facilitates with a person should be answered during the design process.

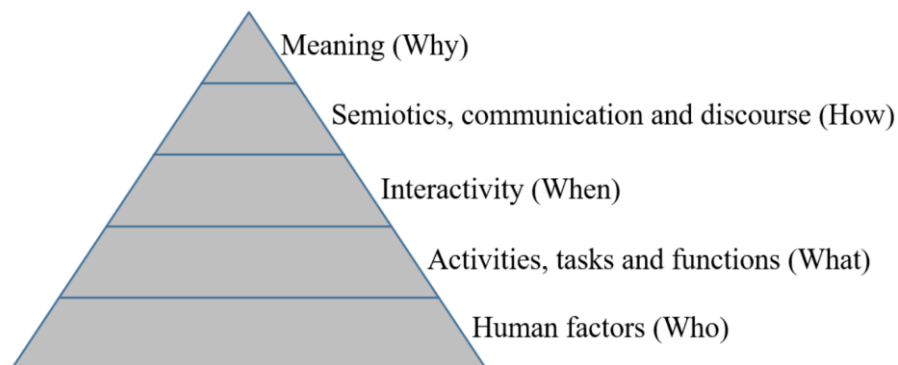


Figure 1 The human-centred design pyramid. Redrawn from Giacomini (2014).

The literature on socio-technical systems identifies the failure of improvement projects in work environments to rely on deficiencies when considering the technological and personnel sub-systems and how one will be affected by changes in the other (Hendrick & Kleiner, 2016). Four important elements of work systems have been identified within socio-technical systems: 1) personnel sub-system, 2) technological sub-system, 3) external environment and 4) organisational design (Hendrick & Kleiner, 2016: p.22).

Researchers studying support tools for operators have highlighted the importance of considering the user, tasks and context within which the technology is to be used (Järvenpää & Lanz, 2015). This is similar to an ISO standard<sup>1</sup> on human-centred design, which calls for

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<sup>1</sup> ISO 9241-210 “Ergonomics of human-system interaction: Human-centred design for interactive systems”.

explicit understanding of users, tasks and environments (Giacomin, 2014). Stahre and Johansson (1994) constructed a methodology named TEAM (task evaluation and analysis methodology), aimed at making specifications for education, decision-making support and work tasks for which operators should be trained. Using a five-step process involving the operators, the tasks are then evaluated in further detail and conclusions drawn on whether operators need support in performing them through training, education or decision-making support.

Considering this and adopting a systemic view whilst being aware that operators do not work in isolation but as part of a whole (a socio-technical system), the framework presented by Karlsson has been chosen to encompass the research presented in this thesis. Extensions and adaptations were made to increase the suitability and clarity of research presented in this thesis, see Figure 2. The reasons for selecting this specific framework were that it made obtaining an overview easy and included aspects that were deemed important (operator, tasks and support tool). It also specified different levels of abstraction.

The system boundaries would include the company that employs the operators and the activities performed to achieve its goals; typically value-creation for customers. Thus, a fourth layer was added to the original three-level hierarchy to emphasise the company connection. Moreover, three adaptations (albeit generic ones) were made within the model to specify the area being researched. The *operator* would be the user, existing and interacting within a team or shift (still called “user collective” since other roles might be present). The artefact would be the *support tool* being considered, existing and interacting within a *group of tools* (all used by operators) and all part of the company’s information system (fourth layer). The fourth layer in the activity cornerstone is called “create customer value/run production” and should be the reason that activities are initiated.

Thus, the four cornerstones within this framework (Operator-support tool) are:

- *Users*, spanning from operators to company level.
- *Activity*, ranging from single actions to running production.
- *Support tools*, depicting any kind of information and communication support.
- *Goal/ Consequence*, concerning evaluations of the fit between cornerstones.

The ellipse represents the context within which the company and operators exist and must perform.

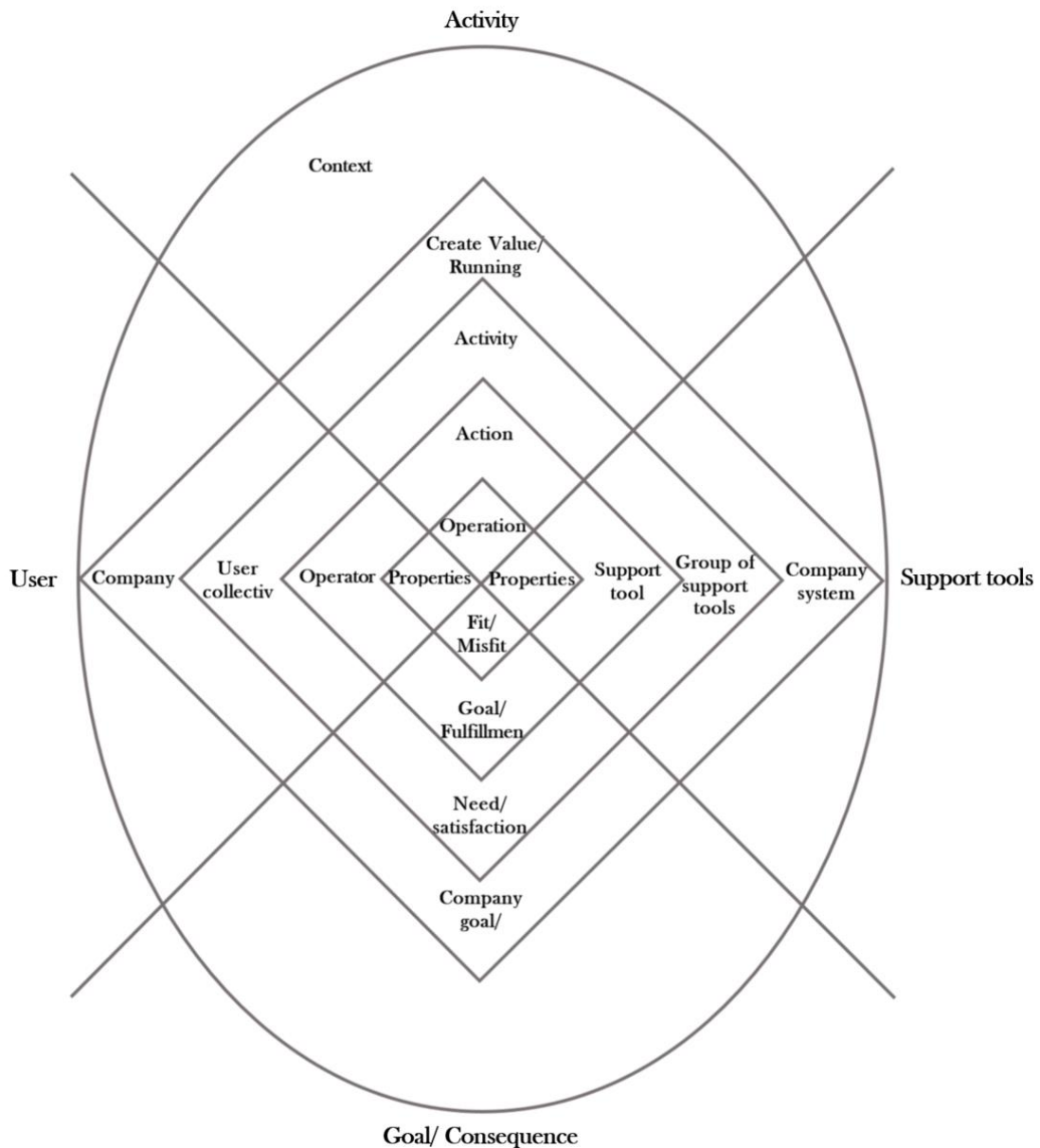


Figure 2 Operator-support tool framework for studying operators and support tools using a systems view. Adapted and extended from (Marianne Karlsson, 1996).

A well-functioning production system requires horizontal as well as vertical alignment in the model. Thus, it requires alignment between layers in the cornerstones as well as within each layer between the different cornerstones. As stressed within this section, studies of the present situation and how to develop it further mean that attention must be paid to all cornerstones.

Despite its proximity to design research, the work presented within this thesis should not be classified as such. As Hevner et al. (2004) states, the outcome of design research (in information systems) should be a purposeful (IT) artefact created to address a problem. This is not the aim being striven for here<sup>2</sup>.

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<sup>2</sup> Parentheses have been added in this thesis.



## 2.5 Purpose and Scope of Research

This section looks at how the scope and purpose of the research have been expounded so as to clarify its nature and the system boundaries.

The Operator-support tool framework presented in previous section was used to scope the research questions. This allows a systems view to be used, putting the questions into perspective and clarifying their boundaries. It also illustrates important aspects to consider while researching the questions. As stated in the introduction, the aim of this licentiate thesis is to contribute to a better understanding of what operator challenges can be supported by ICT tools and how to evaluate this support. The aim and research questions state the purpose of this research as exploratory in nature. It seeks to explore ICT-related phenomena and thus expand current knowledge.

A holistic view and systems perspective were adopted in approaching the first question. The question of operators and their tasks was specified in a way that made them natural focal points. Operators generally work in teams, so the assumption is that both individual operators and the team need studying. This allows challenges linked to interactions between the individual operator and the team to be studied. Current support tools and tasks were also included in the system boundaries, to better understand and identify the issues faced by operators<sup>3</sup>. The connection in terms of information and communication exchange between operators and surrounding support functions (such as logistics and the company) were also included to some extent. This is marked with an arrow in the figure.

The scope of the first research question in the Operator-support tool framework is marked by a shaded area and an arrow, see Figure 3. Tasks are considered as both activities and actions within the framework. The main emphasis was on the connections and interfaces between areas and not individual areas.

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<sup>3</sup> See rationale in the previous section about selection of the Operator-support tool framework.

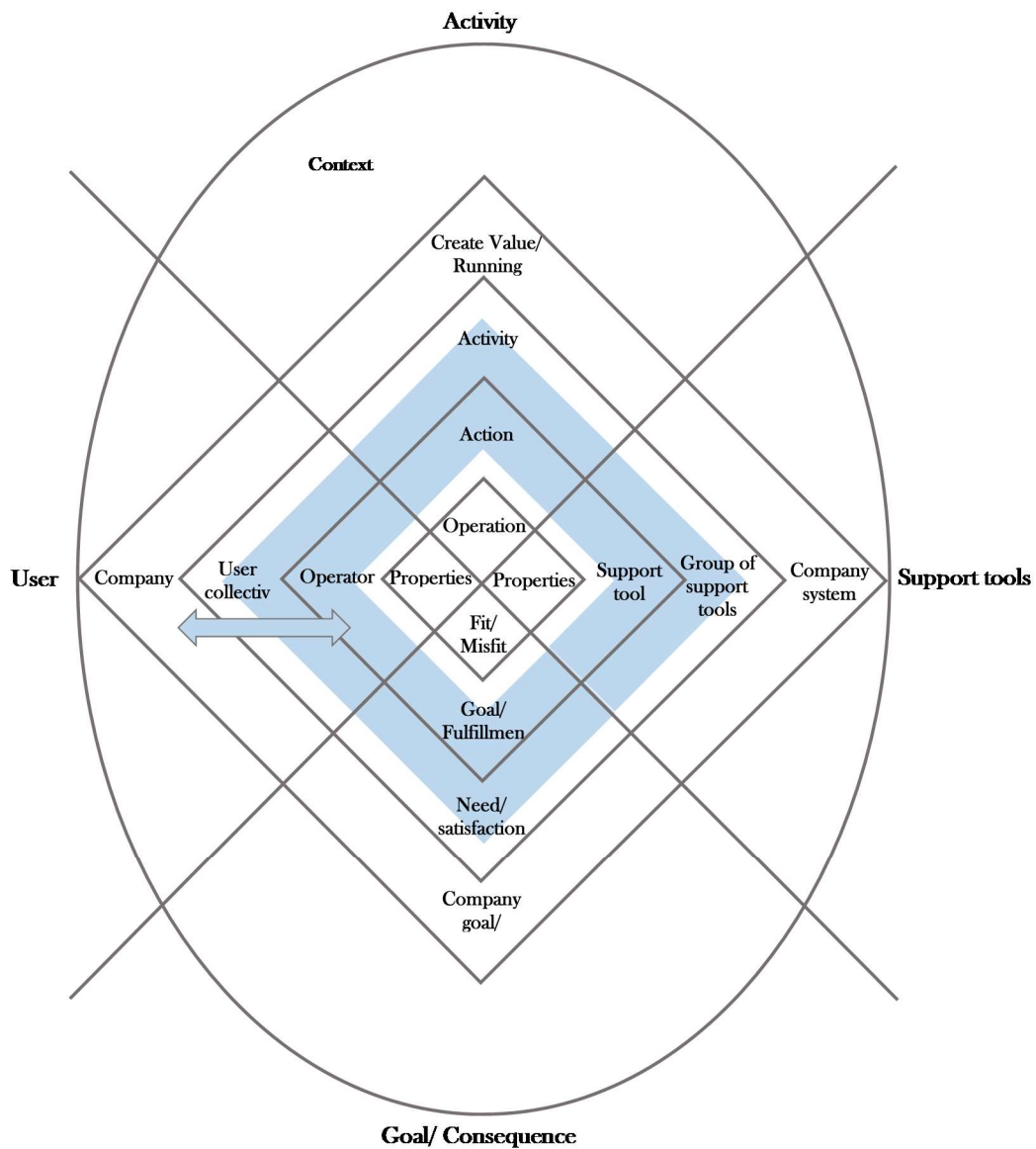


Figure 3 Framing of research question 1 shaded area and double-headed arrow.

The second and third research questions were framed as indicated in Figure 4. The second research question deals with how the ICT tool might support the individual operator, the team or shifts in a department with challenges arising during their tasks (actions and activities). In Figure 4, this is marked by an arrow based in the support tool cornerstone passing through the activities and actions and ending in the operator and user collective layers in the user cornerstone. Hence, this question is approached from the viewpoint of support tools fitting the tasks in a way that suits the operators.

The third research question deals with evaluating the impact of the information and communication support. In Figure 4, this is marked as a circle around the words goal/consequence. The reason for not specifying in more detail was to emphasise the holistic approach to the question and thus potentially include performance measures from the whole Operator-support tool framework.

This section has presented the scope of the research questions. The next chapter presents the research design and methods used.

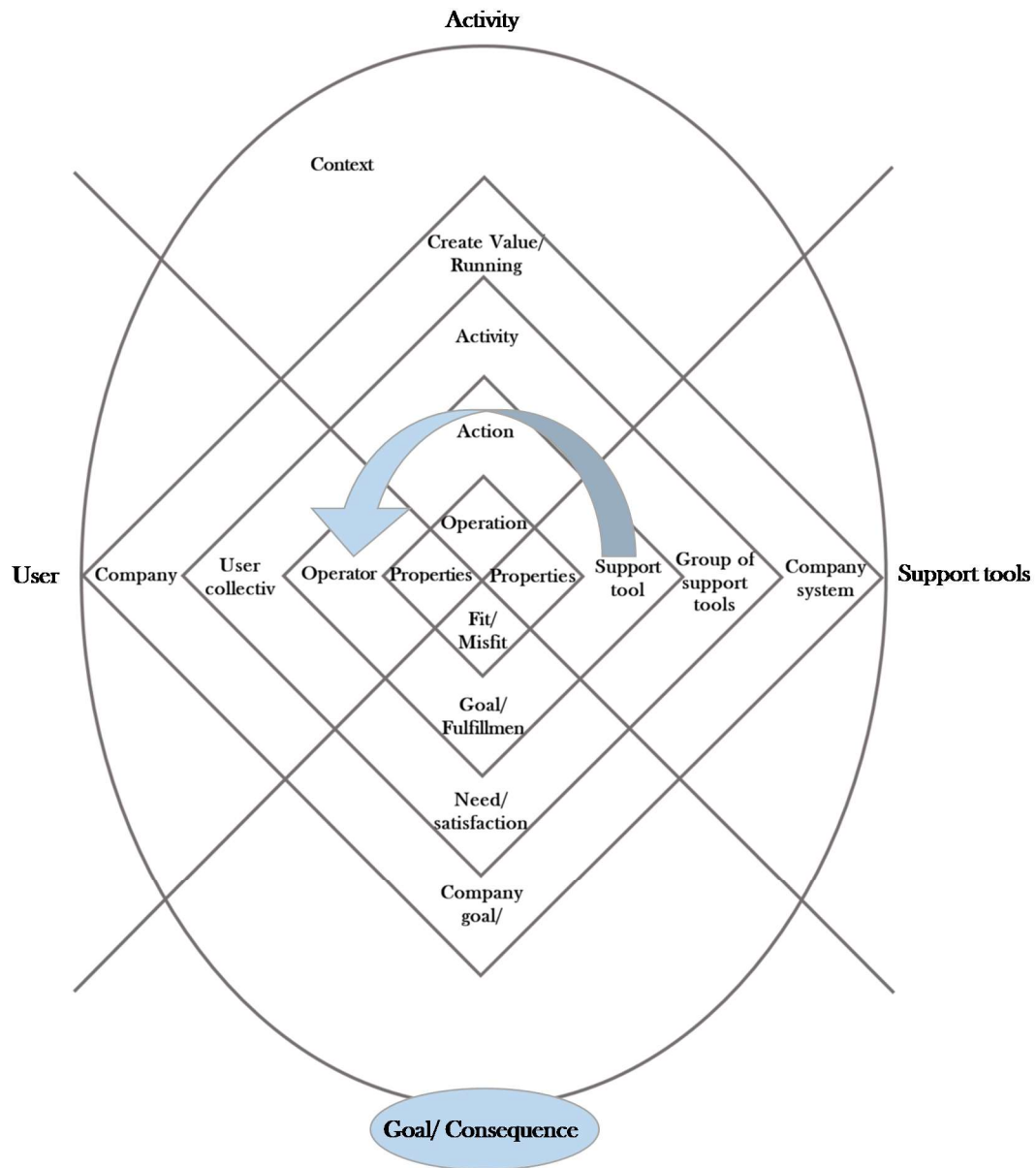


Figure 4 Framing of research questions 2 and 3, marked with an arrow and a circle respectively.



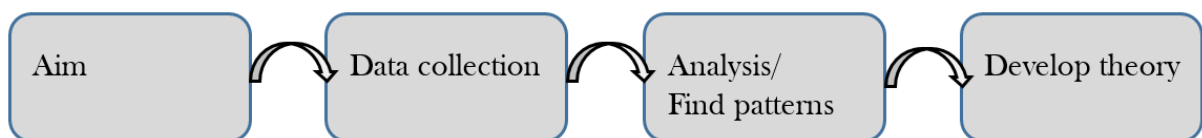
# 3

## Research Methodology

*This chapter introduces the research procedure used to get to the aim and research questions and presents the methods used.*

### 3.1 Inductive Research Procedure

Theory can be tested or built through deduction or induction (Bryman & Bell, 2011; Creswell, 2013). Inductive research starts with studies of the phenomenon. Findings are analysed; patterns sought. Thereafter, comparisons with existing theories are drawn and the theories updated if pieces of the puzzle are found (Creswell, 2013). As discussed in previous chapters, the research questions were constructed and approached with empirical research in mind; something which could be facilitated by either inductive or deductive procedures. An inductive procedure was deemed a better way to allow an emphasis on the explorative aspects. This allows conducting the studies without preconceiving answers to the research questions. It also allowed thorough study of the upper three cornerstones of the Operator-support tool framework; user, activity and support tool. Thus, theory within this thesis has been approached and built through inductive reasoning, stemming from the empirical findings. Figure 5 shows the schematic research procedure used.



*Figure 5 The inductive research procedure followed.*

The aim and research questions were expounded in the previous two chapters and will thus not be explored further. The next section introduces the research design which delimits the possible data collection methods. There then follow descriptions of the individual methods used to collect and analyse data and a description of individual studies contributing to the appended publications. The methodology chapter closes with a section introducing ethical concerns.

However, before delving further into the research design and specific methods, the research strategy affecting (and influencing) data collection and analysis will be introduced. The research approach according to (Creswell, 2013) and research strategy according to (Bryman & Bell, 2011) concern the taking of a quantitative, qualitative or mixed-methods stance towards research. This should be elucidated before, or distinctly, from the research design and is the chosen standpoint of this thesis. However, others consider decisions on the use of quantitative, qualitative or mixed-methods to be part of research design (Denscombe, 2009).

Purely quantitative and qualitative approaches (although these barely exist) would be on the extremes on a scale, using only applicable research methods from either side. Conversely, the mixed-methods approach would be a compromise between the two; using methods from both approaches (Creswell, 2013).

The research questions in this thesis are exploratory in nature. Use of a qualitative approach is quite common in exploratory research (Creswell, 2013). However, multiple methods and indeed a mixed-methods approach is motivated to widen the horizon when either quantitative or qualitative approaches alone would be insufficient in understanding a phenomenon or research problem. Utilising a mainly quantitative approach was considered insufficient for the explorative purpose of the research. A qualitative approach could be used and, as indicated above, is often used in combination with explorative research. However, to widen the scope and ensure detailed results and a wide participant base, a mixed-methods approach was considered best. Thus, exploration through a mixed-methods research approach was favoured. This allowed use and exploration of the advantages of different methods.

## 3.2 Research design

The research design should describe the elements of the investigation, a rationale for the choice of research strategy and an explanation of how key components of research projects link together (Denscombe, 2009). Exploratory research should have a degree of flexibility and potential for development inherent in its design, although it should be used carefully (Denscombe, 2009). Yin (2014) considers the explorative nature as a possible fit for any of the five research designs: experiment, survey, archival analysis, history and case study.

Two study types were carried out to answer the research questions: case studies and survey studies. One reason for selecting these types was the possibility of incorporating the inductive approach and empirical studies into the natural environment of the phenomenon. The selected research design affects (and to some extent limits) the possible methods of data collection and analysis and opportunities to develop theory. The types of studies and methods of data collection and analysis are presented in Figure 6. Reasons and implications will then be discussed for each of them.

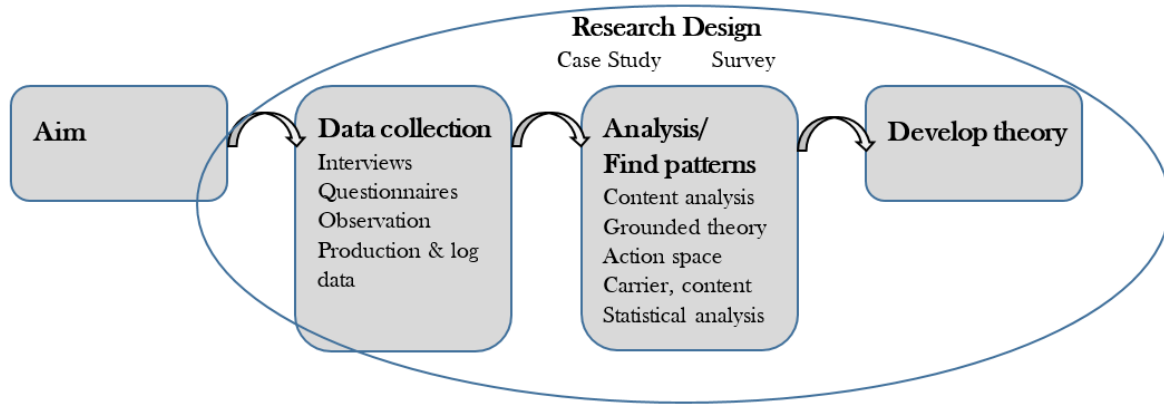


Figure 6 The research design and methods used for data collection and analysis.

### 3.2.1 Case study

A case study gives in-depth information and knowledge on a specific case (Creswell, 2013). A case study is defined as an empirical enquiry investigating a contemporary phenomenon in a real-world context. Case studies are especially suitable when boundaries between phenomenon and context are hard to define (Yin, 2014). A common concern for case studies relates to how generalisations can be made based on findings from one or a few cases (Denscombe, 2009). Yin (2014) states that results would be generalisable to theoretical propositions and thus not to other cases.

The first and second research questions address contemporary phenomena which (especially in the first question) are hard to define and distinct from the environment. An in-depth understanding of the operators' present work tasks and environment was required to reach a broad understanding leading to the challenges and potential improvements that were identified. It was also considered beneficial for the second research question to be answered through case studies, to allow in-depth insights to be gained that were suitable for the environment gained. Simulating and replicating industrial operators' work to gain insights into their challenges was not considered viable due to the time and effort required, plus the risk of omitting factors of potential importance in detecting challenges. From this background the case study research design was selected. This decision is consistent with recommendations from design theory, as discussed in Section 2.4, that to better comprehend the situation, a usage situation should be studied within the natural environment.

To widen the scope and enable generalisation, multiple cases were studied, whilst maintaining a focus on the in-depth characteristics. If the focus were to turn to the comparison itself, Bryman and Bell (2011) suggested using the comparative research design.

The studies may be conducted as cross-sectional (studying a phenomenon at a given time) or longitudinal (studying the phenomenon over an extended period of time) (Denscombe, 2009). Both were selected to suit the different research questions. An in-depth view at a certain time was considered appropriate for the first research question. For the second and third research questions however, longitudinal studies would be most beneficial; studying and evaluating how ICT tools supported operators over an extended period. This could provide insights which could not be obtained from short tests.

The choice to use case studies limited the researchers' capacity to control the course of events and the phenomenon. In addition to this limited control, the selection has further inherent limitations. For example, the results may change if a study is replicated at the same place since interaction with the phenomena could alter it. Thus, the choice of case might affect the results obtained.

### 3.2.2 Survey

The use of survey design has been suggested for cross-sectional studies that are aiming for breadth by capturing multiple viewpoints (Denscombe, 2009). It is often used when the aim is to generalise from a sample to a population on a specific topic (Fowler Jr, 2013). A sampling procedure is beneficial although there are studies which attempt to capture the entire population (Fowler Jr, 2013).

The survey used in this thesis was in the form of a questionnaire, so that theoretical propositions could be generalised. The aim was to capture answers from the entire population (of operators in the studies) and hence widen the base of respondents beyond what would be possible, given the limited time, in the other types of design. Another reason for choosing this design was that it enables analysis of a contemporary phenomenon through quantification.

## 3.3 Data collection

The use of multiple data collection methods has been encouraged within case studies (Yin, 2014). A mixed-methods approach also supports the use of different data collection methods. Applying several complimentary quantitative and qualitative collection methods gives different perspectives on the same phenomena and offers a more holistic understanding. A variety of data collection methods have therefore been used throughout the studies, the rationale for which will be presented below. See Section 3.5.1 for details of the studies that were conducted.

### 3.3.1 Semi-Structured Interviews

Interviews can be conducted using either of three main forms: structured, semi-structured or unstructured, each with their own benefits. The semi-structured interview uses an interview guide to cover important points, but adaptations can be made and open questions are encouraged (O'gorman & Macintosh, 2015). The structured interview does not allow for adaptations but is less time-consuming. Unstructured interviews require more time and initial familiarity but can yield in-depth knowledge (O'gorman & Macintosh, 2015).

The interviews conducted were semi-structured in nature, allowing the researcher flexibility to continue topics of interest to specific respondents and the option of deeper understanding of the challenges faced by operators. Other reasons for this choice included a desire to compare results between cases, decreased reliance on a single researcher and ensuring coverage of basic topics.

### 3.3.2 Questionnaire

Questionnaires are good for collecting information from multiple respondents without the researcher being present, but there is a risk of low response rates (Kothari, 2004). Questionnaires often use closed questions to allow quantification and ensure questions are intelligible (Bryman & Bell, 2011). Questionnaires were selected so that responses could be collected from the whole population of operators at the studied sites. They also enabled distribution of the questions to operators who had not been present when the researchers visited. This also decreased the researcher's control of the distribution and reduced the risk of researcher influence or bias. The questionnaires were self-administered, as described by O'gorman and Macintosh (2015).



### 3.3.3 Direct observation

Direct observation allows a researcher to add dimensions to, and increase understanding of, the context or phenomenon being studied. More specifically, observations can be invaluable aids in understanding the actual use of technology (Yin, 2014). Having multiple observers is advantageous as it increases the reliability of observations (Yin, 2014). The studies in this thesis involved observations of work practices and use of support technology. This method was chosen to compliment the understanding gained during interviews. It also allowed the researcher to see the work, use and work environment. This was deemed important, as it could deviate from the interview findings.

### 3.3.4 Production data and log data

Data can also be collected from available databases (O'gorman & Macintosh, 2015). Within a manufacturing company, databases can be populated and maintained to keep track of tasks and completed processes or to evaluate production performance. Data collected for purposes other than the study in question might be called secondary data (Kothari, 2004). Secondary data may save time during collection, but the researcher has little control of the variables and initial collection process (O'gorman & Macintosh, 2015). Company databases (secondary data) was used as a possible source of information, allowing insight into occurring trends and changes. Using data from these databases also yielded considerable time savings.

## 3.4 Analysis

Mixed methods were used, as indicated in the introduction to this chapter. Thus, a variety of methods are presented within this section.

### 3.4.1 Content analysis and Grounded Theory

Content analysis concerns analysing the content of written or oral material (often transcribed). From the early 20<sup>th</sup> Century when it was a mainly quantitative method of counting certain characteristics, it evolved into a mainly qualitative method of studying the general message (Kothari, 2004). Related to content analysis is grounded theory. This can be used to generate categories or identify areas in common between different sources (Creswell, 2013). Moreover, grounded theory allows analytic categories to emerge from the data, letting the data speak through an iterative process of data collection and analysis (Charmaz, 2014). Grounded theory was selected for the analysis of interview materials, to generate categories, general topics and theory. It also gives insight into when saturation has been reached through awareness of new categories or when variations of them occur. Content analysis was also selected for some studies to generate some broad topics after the data collection had ended. Quantitative and qualitative analyses were both found to be appropriate for comparing opinions.

### 3.4.2 Action space

An operator's work and action space can be studied using the seventeen tasks in Role Allotment, (Fast-Berglund & Stahre, 2013), introduced in Section 2.1. Based on data from interviews and observations, Role Allotment was chosen so as to allow comparison between cases and quantification of the tasks an operator performs. It was also possible to obtain a general description of the range of responsibilities. Interview and observation data was used for the analysis.

### 3.4.3 Carrier and content

Information carrier denotes the carrier of the information (screen or paper for example). Content denotes what is being presented (the actual data or information) plus the mode (picture, text and so on) (Fässberg et al., 2012). Knowledge on the information carrier and content was considered beneficial and contributed to knowledge on issues with current ICT tools. Interview and observation data was used for the analysis.

### 3.4.4 Statistical analysis

There is a vast assortment of statistical analyses which can be carried out, such as statistical significance testing or inferential statistical tests and such things as the confidence interval and effect size can be reported (Creswell, 2013). There are also less advanced statistics such as descriptive statistics; means and ranges for example (Creswell, 2013). Descriptive statistical methods were selected to gain insight into the population being studied. It also allowed the study of production and log data over time.

## 3.5 Introducing the appended publications and contributing projects

The four appended publications are the results of combinations of the studies carried out under the research project *Operator of the Future* plus the results of the *Complex* research project. The projects, case studies carried out and appended publications are summarised in Figure 7.

Within the *Operator of the Future*<sup>4</sup> project, the goal was to develop a toolbox for competent individuals working close to production processes (such as operators), to enhance their capacity. These tools should be based on mobile communication, decision-making support and IT as well as being grounded in a thorough study of operators' need for support involving information or communication. The author of this thesis participated throughout the project and further details of the data collection carried out during it are presented in next Section, 3.5.1.

The focus of the research project *Complex (Support for Operations and Man-hour Planning in Complex Production)*<sup>5</sup> was to develop generic models and methods to support strategies, planning, managing and optimising of complex production. The CXI method was developed within this project. The *Complex* project had mostly been carried out before this researcher joined. Data from the *Complex* project was considered as secondary data by this researcher. The data utilised from the project consisted of collected CXI questionnaires and these contributed to publication D, see Figure 7.

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<sup>4</sup> <http://www.chalmers.se/en/projects/Pages/Operator%20of%20the%20Future.aspx>

<sup>5</sup> <https://www.chalmers.se/en/projects/Pages/Support%20for%20Operation%20and%20Man-Hour%20Planning%20in%20Complex%20Production.aspx>

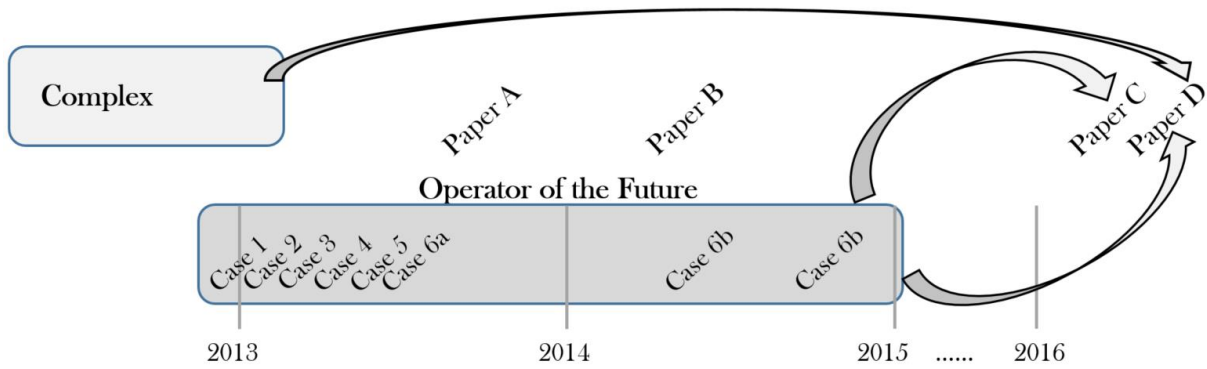


Figure 7 Details of research procedure with contributing publications, research projects and case studies.

As indicated in Figure 7 three of the appended publications stem solely from the *Operator of the Future* project. Similarly, the fourth publication contained data from this project as well as further data from the *Complex* project. The studies presented within the appended publications are all exploratory in nature. However, their aims differ so they used different sets of methods for data collection and analysis. A summary of the methods used in the publications is given in Table 3.

For the remainder of this thesis, the research will be referred to in terms of these publications.

Table 3 Summary of methods used within each publication.

Publication	A	B	C	D
Research Design	Multiple Case study (3 cases)	Multiple Case study (6 cases)	Single Case study (1 case)	Survey study
	Field-Study Cross-sectional	Field-Study Cross-sectional	Field-Study Longitudinal	Cross-sectional
Quantitative data and analysis	Questionnaire: CXI, ICT HW <sup>6</sup>	Questionnaire : CXI RA <sup>7</sup>	Questionnaire : follow up Database Content analysis	Questionnaire : CXI
Qualitative data and analysis	Observation Interviews Grounded theory	Interviews Op effecting <sup>8</sup>	Interviews Observation Content analysis	CXI – (comment field)
Participants	39 questionnaire 22 interview	79 CXI Interview <sup>9</sup>	21 questionnaire 10 Interview	112 CXI <sup>10</sup>

<sup>6</sup> Refers to questionnaire: Assessment of technologies used and benefit of certain functions

<sup>7</sup> Refers to Role Allotment

<sup>8</sup> Refers to analysis of operators' influence within the company

<sup>9</sup> The number of interviews conducted are not specified in the paper. All interviews subsequently carried out in the cases contributed to the understanding and analysis.

<sup>10</sup> Including the surveys from paper B.

### 3.5.1 Data collection and analysis within the Operator of the Future project

As indicated in Figure 7, six case studies were carried out within the project. The cases 1-6a were all present-state analyses using the same data collection and analysis methods. Typically, all data was collected during visits to the production facilities lasting one to three days, although questionnaires were sent beforehand (afterwards in cases 1 and 2). Case 2 was later exchanged, resulting in one of the questionnaires not being implemented. Table 4 introduces the contexts of the case studies. The data collection methods used are shown, as well as the number of respondents in each case.

Case 6b was differently designed; it studied the introduction of an ICT support tool to the operators in a specific department. This case study was borderline action research; a field experiment was conducted in which a support tool was tested (Åkerman et al., 2014)<sup>11</sup>. The test took place between study 6a and the first of the studies 6b. The assessment is that study 6b should be considered a case study as the participatory elements within it were not prominent enough. In other words, the researcher was not involved in planning and executing the change to the extent indicated in literature, so the study could not be considered action research (O'gorman & Macintosh, 2015; Reason & Bradbury, 2001).

The researcher participated actively in all case studies and with all data collection (such as interviews and observations) conducted within them. Hence, a deep knowledge of the cases was attained.

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<sup>11</sup> N.b. this is not among the appended papers.

Table 4 Summary of characteristics, methods and participants within the case studies.

Study/ Characteristic	1	2	3	4	5	6a	6b <sup>12</sup>
Manufacturing process	Metal cutting, assembly	Process surveillance, testing	Assembly	Process surveillance, testing	Metal cutting, assembly	Heat treatment	Heat treatment
Operator expertise	Varying most experts	experts	experts	varying	varying	varying	varying
Department size	53	unclear	20	25	20	25-30	25-30
<b>Semi-structured interview respondents</b>							
Operators	11	2	10	5	7	5	0/10
Production Manager	2	1	2	2	1	1	0/1
Technician	2		2	1		1	
Maintenance				1			0/1
<b>Questionnaire respondents</b>							
CXI	13	9	11	10	7	16	
Technology use	18		11	15	7	14	
Follow up							8/21
Observation	Used	Used	Used	Used	Used	Used	Used

Details of the data collection are given below for areas where additional details are required.

### Interviews

The interviews in all studies were carried out close to the production departments being studied, thus in the respondents' familiar work environment. This gave ecological validity and a feeling of security for the operators. Several interviews ended with the respondents showing points of interest in their work environment, to further emphasise or explain an issue being discussed.

#### *Selections of participants*

Snowball sampling, letting one respondent suggest the next one, (Goodman, 1961; O'gorman & Macintosh, 2015) was used. Specific people were requested, if they were found interesting in previous interviews. A saturation approach (Charmaz, 2014) was used to collect as many interviews as necessary. This approach has been criticised due to the difficulties of proving saturation (Charmaz, 2014). Within the studies presented here, the risk of stopping with too few participants was reduced by visiting several shifts (if applicable), ensuring respondents with different roles and levels of experience were interviewed and by using grounded theory analysis. The interviews were voluntary but encouraged and all operators interested in participating were admitted.

<sup>12</sup> Data gathered on two occasions, June and November 2014.

There was no selection beyond that mentioned above and, despite a wide variety of respondents' characteristics having been included, no conclusions can be drawn as to whether the samples were representative or not.

### **Questionnaire**

Two questionnaires were used in the case studies 1-6a, (*CXI* and *Technology used*). The third questionnaire was used in case 6b to follow up the introduction of a support tool. The questionnaires were generally distributed through the department managers to all operators in the department being studied and anonymously collected in envelopes or at designated locations. All questionnaires used closed questions (other than in the closing comment fields) to contribute to intelligibility and enable quantification.

#### *Assessment of Perceived Production Complexity*

In all cases, how operators perceived production complexity at their workstations was studied using the CXI method. The CXI questionnaire was analysed by reviewing the index and the causes of high levels of complexity at either station or complexity-element level. The procedure (*Publication D*) was therefore followed.

#### *Assessment of technologies used and benefits of certain functions*

The type of technologies operators use in work and leisure was evaluated using this questionnaire consisting of six questions. It was developed within the project *Operator of the Future* (Malin Karlsson et al., 2014). The results were analysed quantitatively and groups compared based on characteristics, use and perceived benefits.

#### *Follow-up questionnaire*

This questionnaire was developed to make a quantitative assessment of changes occurring based on the introduction of a digital mobile ICT tool. It was distributed according to shift overlaps and interviews regarding the same device. The 19 questions covered the operators' perceptions of the following areas; (1) the work situation (2) how well the preventative maintenance worked (3) information (4) work instructions (5) the mobile application. During development, the questionnaire was tested on research colleagues.

### **Direct observations**

Most case studies involved two observers and questions were asked to elucidate unclear situations. This was therefore an unstructured qualitative observation method, as described by Creswell (2013).

### **Production and log data**

Production data was gathered from systems already in place, in the form of maintenance tasks not performed on time and total error reporting. Data covered the periods before and after introduction of the support tool. Data was also gathered on the number of unique weekly logins when the ICT tool was introduced. These data sets were analysed quantitatively using a moving average and trends occurring.

## **3.6 Ethics**

When research is conducted using interviews and otherwise involving humans, ethical considerations are important (Denscombe, 2009). Areas which need consideration beforehand and throughout include, but are not limited to: notifying the intentions, requesting informed consent before participation, not disclosing identities and trying to interpret information correctly (Denscombe, 2009).

Participants in all studies have informed consent to participate in interviews and be observed, with explicit permission requested and given for all recordings (sound and video). For all types of data collection, the participants were informed personally. For questionnaires, the purpose of the study was notified via an introductory text, No information regarding answers from individual participants has been disclosed to third parties.





# 4

## Summary of Appended Publications

*In this chapter, each appended publication has a short summary introducing the reader to the areas covered.*

### 4.1 Summary publication A - Could the use of ICT tools be the way to increase competitiveness in Swedish industry?

#### *Case*

Three case studies were conducted in departments where operators were mainly supervising machines or processes, or assembling products. The operators were dealing with small to large batch sizes. Two of the cases used shift work.

#### *Aim*

The aim of the publication was to discuss results from the case studies in terms of: whether and how the need for and design of ICT tools would be influenced by 1) communication technology maturity among operators, 2) perceived complexity and 3) social sustainability. There is also a need to discuss other factors affecting the choice and use of ICT tools.

#### *Method*

The data was gathered through questionnaires, semi-structured interviews and observations. The questionnaires covered PPC (using CXI) and ICT use in work and leisure. The results from the survey on ICT use were compared between different age groups and extent of use at leisure compared to work. The observations yielded information on interaction with any current ICT tools, machines and other staff – support functions. The interviews were grounded in the observations and were conducted so as to gain insight into the operators' work and communication and any improvements needed.

#### *Results*

Production complexity is perceived as high within two of the companies, with the third lacking data at the time. The level of adaptation or use of ICT tools was higher at leisure than at work. In all cases, written publication instructions were used, in addition one or more

computer systems were used for other purposes. This publication mentions a number of challenges and suggested improvements, such as: difficulties explaining to someone who is not present, updates to instructions going unnoticed, knowing how issues have been resolved previously. Aspects like product quality and communication efficiency could be influenced if ICT tools could do such things as: enabling multimedia transfer, having instructions to hand when needed, indicating changes, and capturing tacit knowledge.

#### *Conclusion*

Complex work tasks will increase the need for decision-making support tools, especially for new operators. Uncertainty about who the future operator is and what tasks he/she will perform should be solved through adaptability of content and support. Factors like competence and culture will affect the support needed by current and future operators.

## 4.2 Summary publication B - Managing production complexity by empowering workers: six cases

#### *Case*

Six cases were investigated, from six stations in four medium-to-large companies with production sites in Sweden. One of the cases pertains to final assembly, four stations relate to supervision of machining and the last case and station is a mixture of both. Approximately half the stations employed mostly expert operators, while the others had operators of varying expertise levels. All the stations had a high level of perceived production complexity, measured using CXI.

#### *Aim*

The publication presents a study of how companies have empowered their workers. The aim was to describe the empowerment levels according to work tasks and to highlight similarities and differences between the cases.

#### *Method*

The cases are described using two different definitions of empowerment, plus other methods such as role allotment and operators' possibility to influence different levels in their companies. Input for these methods and models was gained by interviews with operators and, in some cases, with managers. The empowerment definitions contain aspects such as: the operators should be given information on the organisation's performance, knowledge on how they can influence performance, power to make decisions affecting performance, task autonomy, attitudinal shaping and self-management.

#### *Results*

The results of the role allotment investigation showed that, on average, the operators were responsible for and conducted a third of the tasks themselves, Figure 8. In the cases involving the highest levels of responsibility, 41-53% of the tasks were conducted by operators, indicating a large range of tasks performed. Operators were provided with knowledge and the chance to influence their performance.

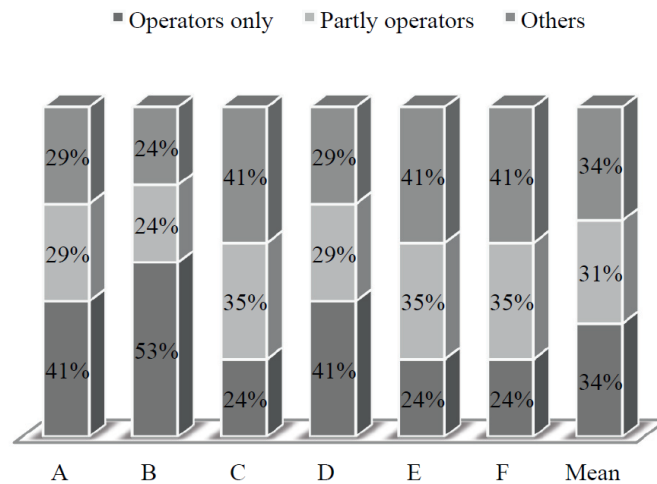


Figure 8 The operators' action space, based on Role Allotment.

### Conclusion

In all cases, the operators are considered to be empowered. Furthermore, the publication gives insight into how managers in some companies perceive their operators and how the operators perceive their work.

The article shows that in order to be empowered (according to these definitions), operators need access to information. It also shows that if they are to make decisions to influence performance, the right information must be accessible whenever and wherever needed.

## 4.3 Summary publication C - Introducing customized ICT for operators in manufacturing

### Case

A large Swedish company developed a mobile application for test implementation in a production department. The mobile application had several functions and was developed with input from the researchers. In the test, it was displayed on smartphones. It was compulsory to use the application in day-to-day preventative maintenance but other functions were not compulsory. For preventative maintenance, operators received cognitive support in the form of information on what checks to perform and how to do them. The operators had to confirm that the checks had been done.

The department, work tasks and process were under development when the test took place. This made it hard to connect improvements in process results with use of an ICT tool.

### Aim

The publication presents empirical findings from the first year of using a mobile application in a department of a large Swedish company. The purpose of the study was to provide an example of how information and communication technology can enable manufacturing operators to perform complex work tasks.

### Method

Quantitative and qualitative data was gathered and analysed. Data was collected from semi-structured interviews, questionnaires, existing databases and databases forming the back-end structure of the application. The respondents' perception of the application was analysed as positive, negative or neutral. Trends in the quantitative data were studied.

### Results

Not all operators used the device. In the survey, 20 out of 21 operators claimed to have used the application to some extent. The department manager was very positive about using the

application and saw several benefits relating to preventative maintenance: “*we have added some checks that the technicians used to do. The operators have been given more responsibilities as we can trust that the work will be done*”. The success of this function should be put down to rigorous preparation and a clear goal regarding what issue needed to be changed.

Error reporting was done in a separate computer system (before and during the test). The test period saw quite a dramatic increase in the number of reported errors. Error reporting in this particular department is very important and all errors should be reported. The operators got better at reporting during the test period.

#### *Conclusion*

The operators were empowered to perform new tasks through a higher general level of process understanding and trust. So, because of the cognitive automation and information-sharing abilities gained by using the mobile application on a smartphone, this case was a success.

## 4.4 Summary publication D - Perceived production complexity – understanding more than parts of a system

#### *Case*

This article presented a collection of previous studies of 112 responses to the CXI questionnaire, from 36 stations at seven large companies (1,000- 6,000 employees). Assembly stations accounted for 70% and machine supervision for 30% of the stations. Industries represented are automotive, powered appliances, tooling and medical appliances.

#### *Aim*

The aim of this publication was to measure and analyse the perceived production complexity from an operator perspective and discuss how the results could be used to manage complex stations.

#### *Method*

Principal component analysis was used to validate the method. Stations that were considered complex were further analysed by looking at: complexity area contributing to high levels of complexity, the items (questions) of most importance to this result and the information gained in the comment field on possible improvements or changes.

#### *Results*

The area causing the most complexity for operators in assembly stations was work variance, whilst disturbance handling contributed the most complexity in machine supervision stations. Adding to complexity for each complexity area, were: A) station design, with statements on heavy lifts and ergonomics, B) work variance, with statements regarding multiple product variants, and C) disturbance handling, with the statements about product variants being similar to one another. Information overload sometimes made finding information difficult and the environment (with light and sound signals) could be challenging to work in.

#### *Conclusion*

An understanding of a system could be achieved by analysing and measuring perceived production complexity. Generally, work variance was the area contributing most to perceived high levels of production complexity. The study implied that operators may need information support in handling product variants and uncertainties, if they are to perform well.

# 5

## Synthesis of Answers to Research Questions

*This chapter encompasses the answers to the research questions, with each question presented and explained.*

The appended publications all contribute to at least two of three research questions. Table 5 below indicates the contribution of the various publications to each research question.

*Table 5 Contribution of the appended publications to answering each research question.*

	A	B	C	D
RQ 1	X		X	X
RQ 2	X	X	X	X
RQ 3	X	X	X	

### 5.1 Results RQ 1 - What are the challenges operators face in their daily tasks, in complex production environments?

Areas within the appended publications relating to information and communication and deemed challenging to operators were grouped according to issues that appeared similar. These identified challenges are then summarised and explained in general terms, according to what the operator needs to know or do.

1. **Knowing to do how to perform a task under normal conditions (for novice and updated tasks).** Operators need to know how to perform their tasks and which steps to take. After acquiring sufficient experience, this becomes more intuitive. For novice operators, or when tasks change, experience is not enough and instructions are often provided to support operators. In the publications, issues were raised regarding unavailable, insufficient (or redundant) instructions, which could not be moved or was wrongly located. (*Deduced from Publications A, C and D*).
2. **Knowing what to do and how to perform a task during disturbances.** The issues are similar to those for normal conditions. However, the situation may be more stressful, experience is acquired more slowly and information on best practice may not be available. Best practice and how others resolved the issue are often unknown. May be any deviation from normal business such as breakdowns or adjustment of machines, after set-up for example. (*Deduced from Publications A and D*).
3. **Handling variations in a single task.** When product variants are numerous, hard to differentiate and require similar yet distinctive ways of working. Products must often be differentiated quickly and processed correctly. Comparable to error codes, where the solution might differ despite codes being similar. Limited human working memory can make it hard to keep all the details in mind, and hints as to differences are not always given. (*Deduced from Publications A, C and D*).
4. **Performing task(s) and supervising machines or processes at the same time.** When reviewing automatic process steps, it may be necessary to carry out other tasks such as tending to other processes, machines or quality controls. This means visual or audible contact with the machine or process interface may be lost, risking that alarms will go undetected for a time, perhaps causing anxiety and stress. (*Deduced from Publication A*).
5. **Finding and understanding products, machines or process statuses and information.** Process information and statuses may be hard to find and interpret; discovering what went wrong, for example. This may occur after an absence whilst production has continued. The absence could be short or long; operators working in two shifts but no night shift, for example, while production goes on round the clock. (*Deduced from Publication A*).
6. **Passing on information and communicating statuses.** This area includes explaining issues and conveying current statuses to others who are not present. Thus, it incorporates both real-time and situations in which receipt of a message is delayed. It may entail explaining how a situation is perceived visually or through other senses, such as audio or haptics. (*Deduced from Publications A and C*).
7. **Knowing and conveying what tasks have been carried out.** Conveying to others what tasks have been performed, finding information on tasks performed by others and maintaining this over time. An example may be preventative maintenance tasks, which might be carried out by several operators. (*Deduced from Publication C*).
8. **Locating products and materials.** Sometimes there is a need to locate a product within a process flow (such as an assembly line) or locate materials that not in the desired location. Operators in the studies had little support in locating products/materials though in some cases, the location could be retrieved by others. (*Deduced from Publication A*).

- 9. Handling different computer systems.** Interaction with multiple systems is often a requirement for operators. The number of systems and possible similarities between them may make them hard to differentiate and use, or simply tiring. Not all systems are considered user-friendly and they may go neglected or colleagues might be asked for help, to avoid having to interact with the systems. (*Deduced from Publications A and D*).

In a work situation in industry, operators could face combinations of two or more of the identified challenges. One example of this is real-time collaboration, with support or guidance from someone not present. This could trigger a combination of challenges 5 and 6. The challenges include understanding information and describing information. For instance, both parties could be trying to explain what the product looks like or noises from a machine and how it should look or sound.

From the articles, it can be understood that the challenges do not exist in all operator work tasks, or for all operators. Differentiating between the assembly and supervision of machines or processes means that some challenges can be more prominent in certain types of work, as indicated in Table 6. The specific task of maintenance is also represented in the table (based on publication C). It is noteworthy that the supervision of machines and processes (often) includes related tasks such as maintenance and quality control. In the following two tables, X indicates an impact or occurrence whereas ~ indicates a possible or lesser impact or occurrence.

*Table 6 Challenges and occurrence in assembly and machine/process supervision work.*

Challenges	Assembly	Supervision Machine/ process	Maintenance
1	X	X	X
2	~	X	
3	X	~	X
4		X	
5	~	X	
6	~	X	X
7	~	X	X
8	~	~	
9		X	

Some of the identified challenges are influenced by operators' level of expertise and the distance involved. Level of expertise may be important since some challenges occur more often amongst novices than with experienced operators (or vice versa). When process equipment is big or the distance between colleagues increases, then challenges may become more frequent. The impacts of distance and level of expertise are indicated in Table 7.

Table 7 Challenges and influence from operator's level of expertise and distance involved.

Challenges	Experience	Distance
1	X	X
2	X	X
3	X	
4		X
5	X	
6	~	X
7		
8		X
9	~	

## 5.2 Results RQ2 - How can operators in complex production environments be supported in these challenges through digital and mobile ICT tools?

The appended publications offer several suggestions on how operators can get support from ICT tools to handle information and communication-related challenges. As seen in publication C, benefits were gained when the process changed to facilitate and properly support and enforce the use of an ICT support tool.

This question concerns how digital and mobile ICT tools can support operators. However, support may also be given through less advanced tools. Some of the suggested support could be carried out using any type of information carrier, such as paper or hand-held computer, whilst mobile and digital ICT tools would be required to provide some types of support. Thus, the answer is divided into characteristics which can provide support: 1) independent of information carrier, in other words, digital and mobile plus less advanced carriers and 2) through digital and mobile ICT tools/information carriers.

Independent of information carrier:

- More suitable information carrier. (*Deduced from Publication A*).
- Information and instructions with the right information (to hand when needed). (*Deduced from Publications A, B and C*).
  - Having information to hand when needed cannot always be guaranteed if the information carrier is not mobile.
- Educating operators. (*Deduced from Publications C and D*).
- Highlighting important or easily missed information. (*Deduced from Publication D*).
- Present information in an intuitive, effortless and fast way. (*Deduced from Publication D*).

Mobile and digital ICT tool/information carrier:

- Mobile information and instructions to hand when needed. (*Deduced from Publications A, B and C*).
- Different information based on task, experience and responsibilities. (*Deduced from Publication A*).
- Notify when new information available. (*Deduced from Publication D*).
- Enable communication and increase efficiency. (*Deduced from Publication A*).



- Enable storage and easy access to information. (*Deduced from Publication A*).
- Enable transfer of multimedia. (*Deduced from Publications A and C*).
- Allow flexibility when challenges and tasks are changed. (*Deduced from Publication A*).
- Capture some tacit knowledge. (*Deduced from Publication A*).
- Allow immediate reporting of errors, or tasks carried out. (*Deduced from Publication C*)
- Mobile access to systems. (*Deduced from Publication C*).

The support illustrated above can be grouped into characteristics of the support that can be provided using only mobile and digital ICT tools.

- Real-time access to information, systems and interfaces (a machine for example).
- Adaptation of information to suit level of experience, task and responsibilities, as well as enabling learning.
- Notifying updates and changes.
- Communication through different modes.
- Multimedia transfer.
- Storing searchable information, (tacit) knowledge, answers to questions etc.

As indicated in the lists above, some support could be provided through any type of information carrier and would not necessarily require a digital mobile support tool. Relating back to the challenges stated in previous sections, an estimate has been made of which of them could be supported using either type of information carrier, see Table 8. This shows that several challenges have no specific requirements as to the information carrier. Instead, they base it on the information content; how the information is displayed and it is conveyed.

*Table 8 Challenges supported through either mobile and digital ICT tools or independently of information carrier.*

<b>Challenge</b>	<b>Independent of information carrier</b>	<b>Mobile and digital ICT tool/information carrier</b>
1	X	X
2	X	X
3	X	X
4		X
5	~	~
6		X
7	X	X
8		X
9	~	~

### 5.3 Results RQ3 - What performance measures could be used to evaluate effects of digital and mobile ICT tools supporting operators in production environments?

Performance measures were used and suggested within the articles to study changes brought about by modifications to the ICT tools that support operators in their daily work. These performance measures are listed below, grouped by affiliation in the systematic Operator-support tool framework presented in Section 2.4.

### **User**

- Attraction of new work force. (*Deduced from Publication A*).
- Empowerment level. (*Deduced from Publication B*).
- Organisational support of ICT use. (*Deduced from Publication C*).
- Process/production system knowledge. (*Deduced from Publication C*).
- Social sustainability. (*Deduced from Publication A*).
- Trust. (*Deduced from Publication C*).

### **Support tool**

- Use of ICT tool – logged data + operator and manager experience. (*Deduced from Publication C*).
- Use of other systems. Number of reports filed, for example. (*Deduced from Publication C*).

### **Activity/Production**

These measures can be used on different levels, evaluating performance during a single task or, on a higher level, the performance of a department or an entire facility.

- Action space - Role Allotment. (*Deduced from Publication B*).
- Number of operators conducting a task. (*Deduced from Publication C*).
- Change of task description. (*Deduced from Publication C*).
- Performance of tasks or backlog of tasks to perform. (*Deduced from Publication C*).
- Productivity – time or throughput, for example. (*Deduced from Publication C*).
- Product quality – rejection rate or rework level, for example. (*Deduced from Publication A*).

### **Goal/ Consequence**

- Amount of tacit knowledge captured. (*Deduced from Publication A*).
- Communication efficiency. (*Deduced from Publication A*).
- CXI – perceived production complexity. (*Deduced from Publications A, B and D*).
- Operator and manager perception. (*Deduced from Publication C*).
- Usability. (*Deduced from Publication C*).

### **Context**

- Social sustainability. (*Deduced from Publication A*).

The groups of measures suggested above are also marked in the proposed systematic Operator-support tool framework, see Figure 9. These groups are marked as spanning the relevant layers, based on the measures suggested above.





# 6

## Discussion

*This chapter discusses the results obtained and compares them to the findings of other researchers. The chapter is closed with a discussion regarding validity and future work.*

### 6.1 Complex production environment

Research questions 1 and 2 are delimited to operators in complex production environments. The challenges experienced, and support tools needed, to handle work tasks may differ in environments which the operators do not perceive as complex. In *publications A* and *B*, it was concluded that the perceived production complexity was high in all cases studied. Accordingly, all production environments were perceived as complex by the operators. As discussed within the frame of reference, a high level of complexity may negatively affect several factors, such as work environment and other performance indicators. In *publication D*, it was concluded that the areas of Work Variance and Disturbance Handling were the strongest contributors to complexity in assembly and machine supervision stations. The areas of Work Variance and Disturbance Handling are indeed reflected in the challenges identified by this thesis.

Because complexity might affect the challenges which arise and their expression, any support deemed necessary would also be affected by a complex production environment. This supports the delimitation of only considering support for operators in complex production environments. This is despite the possibility that operators in environments not considered complex could also be supported by digital and mobile ICT tools. Some of the experienced complexity could also be addressed by supporting operators who face challenges in their daily tasks. Thus, operators could get support in handling complexity and that complexity might be reduced.

### 6.2 RQ1 What are the challenges operators face in their daily tasks, in complex production environments?

From the discussion later in this section, it is apparent that most of the challenges identified within this thesis have also been addressed by other researchers. However, two additional challenges have been identified by this thesis. Based on the literature discussed in the thesis, one additional challenge and one addition to a description were identified. However, it should be noted that despite the effort to compare the challenges identified by this thesis with those

addressed by other researchers, the literature sample is small. The implications of this are further addressed in the section on future research. Even taking note of this, it is plausible that challenges not yet confirmed in the literature would be apparent if the sample of articles was larger.

To this author's knowledge, no research has focused on general and explicit description of the challenges faced by operators regarding information and communication. None of the articles discussed (or other articles read) listed these challenges clearly. Challenges from literature were derived from general and in-depth descriptions of work procedures and use scenarios. In one of the articles, five out of the nine original challenges could be identified. Therefore, this thesis contributes knowledge on the challenges relating to information and communication that operators may face in their daily tasks.

### 6.2.1 The challenges and their identification in research articles

The first challenge identified is commonly reported and has been addressed by many researchers. However, several of the others are less common in the literature. That said, challenges 1 and 2 are rather similar; the reason for separating them was to emphasise their focuses. The first challenge relates to normal operations and can be expected. However, the second is harder to prepare for or gain experience in, so there would naturally be less supporting documentation. The third challenge could be related to the first, but only emphasises difficulties in differentiation (between such things as product variants, possibly under time pressure) and not what to do once the type or variant is known.

*Italics in the challenge titles were added, based on findings in the literature.*

#### **1. Know what and how to perform a task under normal conditions (for novice and updated tasks).**

This challenge has been reported in various contexts as: semi-automated (physical) processing (Hoarau et al., 2014), maintenance of a control station (Rauh et al., 2015) and operations and assembly (Michalos, Makris, Papakostas, Mourtzis, & Chrysosolouris, 2010). In these, the operators, mainly novices, had issues knowing how to perform the task. Similarly, Morkos et al. (2012), Holm et al. (2017) and Fast-Berglund et al. (2014) identified the challenge in assembly contexts and addressed it by testing other types of training and instructions.

Instructions are often provided to mitigate this challenge, but deficient instructions will contribute to operators being faced with it. Issues with instructions (such as redundant instructions (Fässberg, Fasth, Mattsson, & Stahre, 2011)) have been discussed. In assembly, relatively small distances and movements (such as turning) may be deemed too great an obstacle for them to be used (Thorvald, Högberg, & Case, 2014).

#### **2. Know what and how to perform a task during disturbances.**

This challenge was identified as difficulties in finding best practice for maintenance work in process industry (Aleksy & Rissanen, 2014). Hoarau et al. (2014) identified it when processing products did not yield the desired measurements, best practice was non-existent and many iterations were generally required to get the correct measurements, even by experienced operators. This challenge has also been reported in packing in assembly (Niedersteiner et al., 2015).

#### **3. Handle variations in one task.**

The third issue is often implicitly expressed in introductions to articles on such topics as complexity and mixed-model assembly, because operators need to handle such issues as

product variants or mass customisation (Al-Zuheri et al., 2016; Falck et al., 2017b; Hu et al., 2008; Michalos et al., 2010; Orfi et al., 2011). The issue was also reported by Bäckstrand et al. (2008), who approached it through using clearly visible colour codes (papers) attached to the product.

**4. Perform task(s) and overview machine or process at the same time.**

No articles were identified that confirmed or referred to the challenge.

**5. Find and understand product, machine or process status and information.**

Aleksy and Rissanen (2014) reported this issue when operators who were not experts in the equipment were trying to understand the problem and clues given, so as to then pass the information to service personnel (Challenge 6).

**6. Transfer information and communicate status.**

Difficulties were encountered in describing and passing correct and adequate information about a problem to service personnel (Aleksy & Rissanen, 2014). Collaboration was found to be inefficient due to difficulties in explaining what form it should take. This could be addressed using, say, an image with overlaid hand drawings (Aleksy et al., 2014).

**7. Communicate and know what tasks has been performed.**

This issue has been reported for operators working with maintenance tasks which should be reported as complete (Aleksy & Rissanen, 2014; Rauh et al., 2015).

**8. Locate products, materials and equipment.**

Difficulty finding and identifying the correct process equipment has been reported for maintenance of more extensive processes (Aleksy & Rissanen, 2014; Aleksy et al., 2014). Equipment was added to the challenge title as it is a good fit with the other aspects.

**9. Handle different computer systems.**

No articles were identified that confirmed or referred to the challenge.

**10. Transmit health and safety information in case of emergency.**

Aleksy and Rissanen (2014) and Aleksy et al. (2014) reported this challenge from maintenance within a pulp and paper mill where potentially dangerous gas leaks or other hazardous situations could occur. In an emergency the operator, who may be in a serious condition (perhaps unconscious) would need to contact others to get help. Responders are also at risk of being affected by the same incident (during a gas leak for example) if information is not forwarded. This challenge was added as it complements the list of challenges.

### 6.2.2 Challenges their occurrence and influencers

The articles discussed above provided additional knowledge on when the challenges might occur. In Table 9 and Table 10, any changes have been marked according to what tasks the challenges might entail, plus the influence of proximity and experience. However, it is hard to derive any conclusions due to the small sample of articles from differing industries and types of work. That said, some types of work are marked as having a wider range of challenges. This is likely influenced by the scope being wider and there being less specification of the scope of tasks for supervision of machines/processes. Implications are also stated, based on some challenges being more common than others. It is noteworthy that challenges 1, 6 and 7 seem to be common across different types of work.

*Table 9 Occurrence of challenges in different types of manufacturing work. Additions from the literature are marked.*

Challenges	Assembly	Supervision Machine/pro cess	Maintenance	Process industry - Maintenance
1	X	X	X	
2	~	X		X
3	X	~	X	
4		X		
5	~	X		X
6	~	X	X	X
7	~	X	X	X
8	~	~		X
9		X		
10				X

Not much new information was found regarding the influence of: operators' level of expertise, proximity to the process, distance between operators and movement required, see Table 10. However, the influence of operators' level of experience was further emphasised for challenges 1, 2 and 5. It is noteworthy that without proximity to other operators plus instructions the indications are that some challenges may be anticipated.

*Table 10 Influence of operators' level of experience and proximity on challenges. Additions from the literature are marked.*

Challenges	Experience	Distance
1	X	X
2	X	X
3	X	
4		X
5	X	
6	~	X
7		
8		X
9	~	
10		X

### 6.3 RQ2 How can operators in complex production environments be supported in these challenges through digital and mobile ICT tools?

There are several ways to approach and solve challenges of information and communication, with quite different information carriers being possible. The answer to this question was divided into: 1) possible support to via digital and mobile ICT tools or information carriers and 2) possible support provided independently of information carrier. From the examples of support tools in Chapter 2, it can be concluded that support (or information) could be given through



simple information carriers such as pieces of coloured paper (Bäckstrand et al., 2008). Examples were also given of more advanced carriers such as AR (Morkos et al., 2012). Thus, the support could be more dependent on the information content than the carrier. As stated in *publication D*, information ought to be presented intuitively, effortlessly and quickly.

Consequently, it is not necessarily the most advanced tools that should be chosen to support operators. How to solve a specific situation must depend on the company's information and communication strategy. The introduction of ICT tools which follow a strategy reduces the risk of having redundant and conflicting tools and systems later on. When constructing a company's information and communication support strategy, all cornerstones of the Operator-support tool framework should be considered with regard to the present and future situation. Incorporating all cornerstones (user, activity, support tool and goal/consequence) allows many important aspects to be covered. However, other aspects such as planned (and especially more major) changes in manufacturing or other processes must also be considered so as to ensure compatibility with future manufacturing. This work should therefore be carried out in cooperation between different areas of responsibility in the company and not solely within the IT or manufacturing departments.

Similar consideration should also be made on an operational level when implementing any support tool. For example, aligning the work organisation, how tasks are conducted and the support tool makes it more likely that the tool will become relevant to the operators and that the intended support will be achieved (*publication C*).

Other researchers have approached similar research questions by providing examples of ICT tools that can be used in different contexts (Fässlberg, 2012; Åkerman, 2016). This thesis addresses these questions by using examples of the functions that mobile and digital ICT tools can provide.

Further examples of functions which can be provided by mobile and digital ICT tools may be derived from the literature. Despite the possibility of generating more functions, this has not been done in this thesis; it was not considered meaningful to provide a general list for this topic. Different types of ICT tools could facilitate and enable distinctive sets of functions. Thus, tools are best addressed separately, which is not within the scope of this thesis.

## 6.4 RQ3 What performance measures could be used to evaluate effects of digital and mobile ICT tools supporting operators in production environments?

The third research question is not limited to any specific environment, or any ICT tools supporting operators in specific challenges (as was seen in the first two questions). The reason for excluding these aspects is to allow for a wider perspective. This acknowledges that a tool could be evaluated using similar performance measures, despite differences in environment and reasons for implementation and despite improvement of a support tool.

There is no obvious selection of performance measures with which to evaluate ICT support tools. Modifications to support tools might impact a vast range of areas such as user perception, task performance and production rates, as shown in Section 2.3.2. This indicates the potential of benefits and disadvantages arising in several areas.

The performance measures in the example were therefore divided according to the cornerstones of the framework. From the results, the list of possible performance measures with extensions based on examples from the literature is presented below. Please note that some of these performance measures are merely descriptions of areas that can be evaluated and are not measures in themselves. Various indicators and tools could be used for some of these areas.

## **User**

- Attraction of new work force.
- Collaboration (Dünser et al., 2008).
- Empowerment level.
- Organisational impact (Delone & Mclean, 1992).
- Organisational support of ICT use.
- Process/production system knowledge.
- Social sustainability.
- Trust.

## **Support tool**

- Function of the tool itself ((Niedersteiner et al., 2015).
- Quality of information (Delone & Mclean, 1992).
- Quality of system (Delone & Mclean, 1992).
- Reliability (Aleksy & Rissanen, 2014).
- Use of ICT tool – logged data + operator and manager experience.
- Use of other systems. Number of reports filed, for example.

## **Activity / production**

These measures can be used on different levels, evaluating performance of a single task or, on a higher level the performance of a department or entire facility.

- Action space - Role allotment.
- Number of operators conducting a task.
- Change of task description.
- Performance of tasks or backlog of tasks to perform.
- Productivity – time or throughput, for example.
- Product quality.
- User performance (Dünser et al., 2008).
  - Time (Holm et al., 2017).
  - Quality (Holm et al., 2017).

## **Goal/consequence**

- Amount of tacit knowledge gained.
- Communication efficiency.
- Communication capabilities (Morkos et al., 2012).
- Cost-effectiveness (Aleksy & Rissanen, 2014).
- CXI – perceived production complexity.
- Operator and manager perception.
  - User perception (Dünser et al., 2008).
- Return of Investment (ROI) (Morkos et al., 2012).
- Usability (Dünser et al., 2008; Holm et al., 2017) .
- User satisfaction (Delone & Mclean, 1992).

## **Context**

- (Social) Sustainability.

Although the above list is not exhaustive, there are many possible areas of study for evaluating ICT tools supporting operators. The answer to this research question will vary depending on the context in which the researcher or evaluator belongs. A traditional manufacturing perspective could be to study only what happens with KPIs such as lead time, throughput and quality. Similarly, a business mind could consider the payback time based on these measures. A third might regard usability and the fit between tool and user as most important. This is also indicated in the few similarities when comparing the indicators used by other researchers to those identified within this thesis. It is worth mentioning the use of performance measures from all areas of the Operator-support tool framework, identified in the literature.

Halachmi (2005) indicated that the costs of measuring performance can outweigh the benefits and that results and measures in changing organisations can quickly become obsolete. Therefore, it is important to select relevant and not too many measures, bearing in mind possible organisational changes. It is also advantageous if these measures can be communicated back to the departments and their operators clearly and intelligibly (Larsson, 2017) while also gathering feedback.

Performance measures can be selected subjectively or with support from the methods exemplified by Bhagwat and Sharma (2007) and Cheng and Li (2001) on a business and supply-chain level. Ultimately, decisions on what measures to deploy depend on, or are at least influenced by, the interests of those making the choice. As long as the indicator measures what it is intended to, then it will provide viable information. However, this thesis argues that a wide perspective could be beneficial. Use of multiple evaluation methods and perspectives gives the advantages of a broader exploration of, and input to, benefits and disadvantages. This is supported by the conclusion that it is “*necessary to use a combination of different types of measures as well as on different hierarchical levels*” to support improvement activities (Grunberg, 2007). Hence, an understanding is gained, of both the detail and the whole picture. As seen in the examples of indicators that were given, some are related (or rather easily related) to costs and savings whereas other measures are hard to relate in monetary terms. The relative ease of quantifying some measures could result in other important factors being neglected (Björkman, 1990).

The Operator-support tool framework presented in this thesis could be used to gain a broad perspective and reduce the risk of neglecting important areas and indeed factors. Evaluation options should be used that cover all four cornerstones and from different levels. In other words, those in the inner and outer levels of the framework.

Returning to the list of sample areas for measurement, it is noteworthy that the measures are rather different. Some are more easily quantified, while others could be evaluated qualitatively (user perception, for example). Halachmi (2005) indicates that a qualitative approach also could be beneficial. The required amount of repetitions of the measure varies. Some could be performed on a standalone basis, while others require comparison. The type of knowledge that can be attained by comparison is also different. It allows conclusions regarding changes; something which standalone measures do not. The time horizon of the measures is also different. Some could be evaluated during short tests (such as usability and tool functionality) whereas others require extended periods of use before a viable result can be gained (such as product quality and knowledge of processes/production systems).

Stratopoulos and Dehning (2000) concluded that allowing sufficient time for measures on a higher hierarchical level was a critical factor, see Section 2.3.2. Under the Operator-support tool framework, measures within the inner layers generally require a shorter time (compared to the outer layers) before valuable information can be gained by measurement. Changes within the context would generally require the longest time before differences could be measured. Changes within the context in the model would be too wide for most studies and would require

further resources. Aspects in this area could be related to sustainability (in terms of social and environmental attributes), as indicated by the indicators given.

To summarise, it is important to study the match between the operator-action-support tool layer and between the other layers and the cornerstones presented in the Operator-support tool framework.

## 6.5 Summarising the discussion of ICT tools supporting operators

This thesis has addresses three aspects of ICT tools supporting operators. Firstly, which challenges operators face in relation to information and communication. Secondly, how ICT tools could support operators in identified challenges. Third, performance measures which could be used to evaluate ICT tools supporting operators.

As already shown, operators may face a range of challenges relating to information and communication. Ten different challenges were identified, most of them identifiable in other articles. However, each article only identified some of them. This implies that the challenges faced by operators are different and this was further supported in a comparison between different tasks. Thus, identifying and addressing the challenges by considering the users, tasks and any current support tools is important in all cases; it contributes to the relevance of the ICT tools that support operators in their work. Another reason to identify the challenges is to gain a wider perspective on the later stages of tool development. Once the challenges are recognised, it might be possible to identify several challenges that could be addressed using a single function. This may entail keeping an open mind when searching for suitable ICT tools.

An increasing amount of potential ICT tools are available, and multiple tools could typically address a single challenge. As advocated earlier, a company's information and communication strategy should support a final decision on which tool to use. This supports consistency and compatibility throughout the company.

There are obstacles to deploying support tools and not all investments are successful. As pointed out by several authors, pay-back and cost are important in companies (Aleksy & Rissanen, 2014; Morkos et al., 2012), thus, the choice of evaluation method has a vital role. A simple approach to evaluating an ICT tool is to study a single factor such as quality, throughput, usability or functionality of the tool. However, evaluating different areas which the tool could affect gives a better understanding of the actual benefits and costs involved in its introduction.

The systematic Operator-support tool framework presented and used throughout this thesis (see also Figure 10) has been shown as advantageous in maintaining a wide perspective. It could be used to:

- identify challenges,
- ensure proposed tools support the tasks and fit the system,
- ensure a well-conceived solution and consistency with all layers and cornerstones,
- ensure that an evaluation covers multiple aspects (cornerstones).

The aim of this thesis has been to contribute to a better understanding of what challenges ICT tools can support operators with and how to evaluate this support. Input has been made towards this aim throughout the results and discussion section.

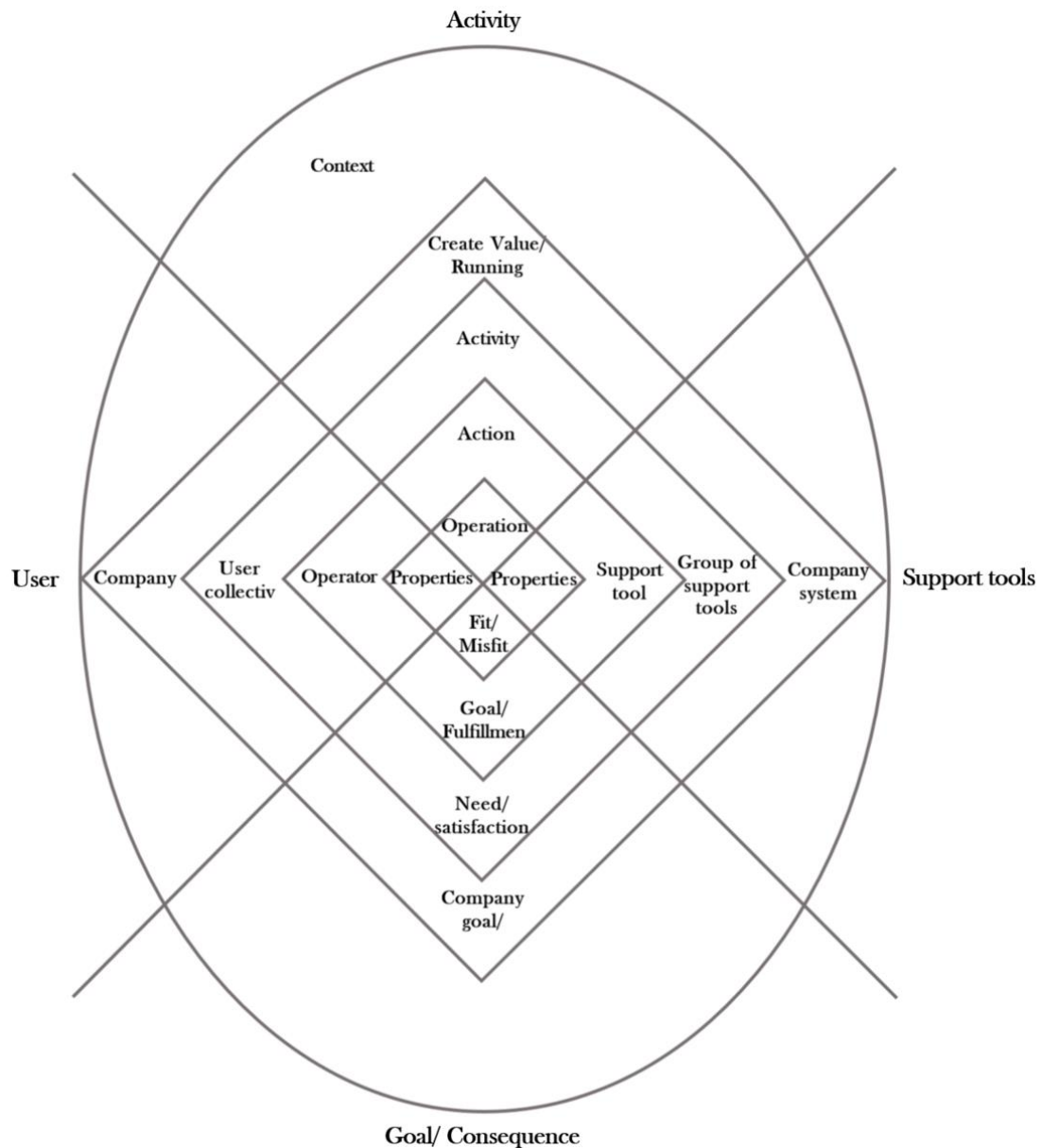


Figure 10 Operator-support tool framework.

### 6.5.1 Approaching improvements to ICT tools supporting operators

The frame of reference in Chapter 2.3.3 two approaches are mentioned: technology push and pull. Within this thesis, specifically in RQ1 and RQ2, the pull approach has been used. This started with an investigation of the challenges operators face in their daily work and then went on to how mobile and digital ICT tools can support operators in those challenges. The selection of which challenges to support would lead to the design phase of a support tool which was well-suited to use in operator work. The aim and results of this thesis were classified as supporting incremental changes; gradual improvement of the information system and cognitive support to operators.

The third research question was classified as relating to each and every approach to changing operator support tools. Despite differences in rationale, changes to or exploration of technology was to be evaluated. Categorising the thesis in the change approach matrix appears in the upper left corner of Table 11.

This thesis argues that research of both technology push and pull is needed. Technology pull contributes a set of challenges and problems. Technology push enables understanding and exploration of the technologies, their capabilities and limitations. From an academic standpoint, all quadrants could pose interesting questions and should all be studied, and as indicated earlier in this thesis so has been the case.

*Table 11 Researched quadrant of the change approach matrix.*

	<b>Technology Pull</b>	<b>Technology Push</b>
<b>Incremental changes</b>	This thesis	
<b>Radical changes</b>		

## 6.6 Validity and Transferability

Judging the quality of research validity and reliability is often mentioned in the literature. The validity and reliability concepts originate from quantitative research but have also been adapted for qualitative research (Denscombe, 2009). Validity relates to the accuracy and quality of the data and analysis (Denscombe, 2009). Ecological validity specifies the validity related to the environment. For example, capturing phenomena in their environment rather than outside it (Bryman & Bell, 2011). Reliability relates to the consistency of data collection methods and techniques (Denscombe, 2009).

Creswell (2013) identified eight strategies for ensuring the validity of qualitative research: triangulation, member checking, rich descriptions, clarify researcher bias, present negative data, spend prolonged time in field, peer debriefing and use of external auditors. The use of data triangulation or multiple sources allows the researcher to investigate a phenomenon from different standpoints whilst reducing the risk of bias (O'gorman & Macintosh, 2015). Denzin (1973) identified four basic types of triangulation: data, investigator, theory and methodological.

Maintenance of research validity was attempted using data, investigator and methodological triangulation. Data triangulation was achieved by using multiple data sources (Denzin, 1973) and by interviewing respondents with different responsibilities, such as operators and managers.

Investigator triangulation was achieved by using two or more interviewers. Interviews and findings were discussed and uncertainties clarified by further interviews, discussions with managers or observations. Multiple researchers were also used during the observations which, according to Yin (2014), increases the reliability. Different methods of data collection were also used to obtain rich data and different perspectives on the phenomenon.

The time spent in field cannot be considered extensive. Nevertheless, sufficient time was taken to gain a thorough understanding of the operators' work. That said, aspects of the operators' work could have been missed at each visit. This means that aspects relating to challenges of information and communication have likely been missed. These could have increased the number and quality of the challenges identified. Accordingly, it is not anticipated that further data and knowledge of work tasks would enable any challenge to be eliminated. Rather, additions and improvements of descriptions may be expected.

Peer debriefing was used by discussing the cases within the research team of the *Operator of the Future* project. This led to further inquiries and additional areas of interest. Member

checking was used in the research project, but not reported in the appended publications, see Future Research. External auditors were used, by peer reviewing appended publications. However, the challenges and suggested performance measures within these were not presented as key areas.

Throughout the data collection, the aim was to maintain a high degree of ecological validity using observations and tests within the factory environment. The interviews were held in the departments of the participants and several interviews included operators explaining points of interest within their environment. Thus, the ecological validity was considered to be high and value-adding.

No extensive literature search was made to identify further challenges and increase the list of performance measures given. Thus, it is likely that further additions (of both challenges and performance measures) could be found. This issue is discussed further under the Future Research section.

The main research design used in this thesis has been case studies. This entails certain limitations such as: reduced researcher control of the phenomenon, the selection of cases affecting the results obtained and no possibility of replicating the study. The reduced control of the phenomenon is a trade-off with the ecological validity which, in these studies, were considered more important. A further reason was the limited possibility of considering all factors which might influence operators' work and need for support. Therefore, using other cases might have yielded different results. However, it is not possible to predict what these differences might be.

Transferability and generalisability of results and methods could also be used to evaluate research. As mentioned in the methodology chapter, the results from case studies should not be generalised for other cases but for theoretical propositions instead (Yin, 2014). Therefore, despite the similarity of challenges between the different companies and researchers mentioned in the thesis, each new context or case study needs investigations of its challenges. The results presented have, without exception, been obtained at Swedish production sites. Similar results might be gained in similar settings. However, as with many case studies, small changes in settings can greatly affect the outcomes. In this particular case, aspects such as culture and ICT maturity of society (to name a couple) could affect the results. These particular aspects are discussed later, to illustrate their importance.

Culture is a factor influencing the results of research relating to humans and thus also affecting generalisability. Some cultural aspects are identified and mentioned in context of this thesis. One aspect concerns the company's perspective on human resources (such as operators). Many of the operators studied are considered experts, which could influence areas such as trust and the extent of their tasks. The complexity and number of responsibilities has been seen to increase the need for support. Sweden has some of the highest levels of ICT maturity and access in the world; ranked at 10<sup>th</sup> place in 2016 (ITU, 2016) and this may influence the perceived usefulness of, and need for, ICT tools. Perceived usefulness of ICT has been reported as higher among frequent users (Chesley, 2010). Similarly, (Malin Karlsson et al., 2014) found a positive correlation between operators using social media and the perceived benefit of sending pictures at work. Research in related areas has shown that user experience and information structure are affected by the culture and origins of the user (Nawaz, 2013; Nawaz & Clemmensen, 2007). Hence, the results are not readily transferable to other countries and contexts.

Accordingly, challenges faced by operators and the possibilities and feasibility of using digital mobile ICT tools to support operators need to be investigated in the particular country and production site. This means that the results of this research cannot be transferred to new cases or contexts.

Nevertheless, it does seem possible to transfer the research approach to new situations, cases and contexts. This is supported by the use of the same design and data collection methods

throughout six cases in the *Operator of the Future* research project. Furthermore, other researchers have also taken similar approaches.

## 6.7 Future work

Several extensions could be identified from this thesis, to refine the results and increase validity. Member checking within the studied cases could contribute to better accuracy, validity and relevance of the challenges described. This stage has been carried out, but at the time of writing of this thesis, it was unpublished and was therefore not included.

A wider selection of cases should be studied to refine descriptions and perhaps identify further challenges. The commonality of the challenged already identified could also be studied through additional cases. An extended literature base, with articles based on cases and trials relating to information and communication support to operators could also contribute in this endeavour. Further literature analysis could also result in the identification of articles addressing challenges 4 and 9, for which no support was found in the literature.

The list of exemplified performance measures could be further extended through a more extensive use of literature. The commonality of use of the measures identified and area measured within the operator-support tool framework could also be studied by using more extensive literature. The measures identified could be evaluated as to their suitability, reliability and validity as evaluation measures of ICT tools supporting operators. These evaluations could be both theoretical and empirical.

The answer to RQ2 could also be further extended, although it was deemed more beneficial to explore different technologies (as discussed in Section 6.3). The possibilities and characteristics of technologies could be compared.

## 6.8 Contribution to academia and industry

The contribution from this thesis to academia and industry are related to the results obtained and the methodology utilized to achieve them. Since the research was designed as case studies the results are not readily transferrable to other cases. However, challenges identified provides opportunity and help, foremost for industry but also for researchers, to compare and detect challenges as not to miss them if present. The approach of finding the challenges would be transferable to other contexts and could be used by both industry and academia. Industry could also be inspired by the answers to the second research question.

Dependent on quadrant in Table 12 best describing a study or an industrial project this thesis could be used differently. Within the top left quadrant the method utilized in this thesis could be used. For projects within the bottom left quadrant the method could be used as a part to investigate the current situation and what to avoid and maintain from it, when radically redesigning operator support. In the right part of the matrix the results, mainly the identified challenges, could serve as inspiration of areas to consider supporting operators with or avoiding to cause issues in.



*Table 12 Possible use of thesis results.*

	<b>Technology Pull</b>	<b>Technology Push</b>
<b>Incremental changes</b>	Method	Results inspiration
<b>Radical changes</b>	Method	Results inspiration

The results of the third research question could be used by industry and researchers as inspiration for selecting performance indicators to evaluate digital and mobile ICT tools. This would ensure a broad evaluation.

The main contribution to academia would be the Operator-support tool framework extended from Marianne Karlsson (1996) and the compiled lists of challenges and performance measures.



# 7

## Conclusion

*This chapter concludes the thesis and makes some brief short comments on its aim and on each research question.*

This thesis has presented and discussed the results of the challenges that ICT tools can support operators with and how this support can be evaluated. It has been found useful to adopt a holistic approach through.

The aim of this licentiate thesis is: *to contribute to a better understanding of what challenges ICT tools can support operators with and how to evaluate this support*. A better understanding can be gained through the answers to the research questions, so the aim of the thesis has been fulfilled.

To provide answers to the research questions supporting the aim, case studies were conducted and the literature was surveyed. In conclusion, short answers to each of the three research questions are provided:

RQ 1) What are the challenges operators face in their daily tasks, in complex production environments?

Surrounded by a complex production environment, numerous challenges could occur in the operators' daily tasks. Ten challenges were identified in this thesis. A couple of these relate to operators understanding their tasks and how to perform them and possible variations on them. Other challenges relate to transferring and understanding information. Which challenges an operator faces depends on factors such as tasks, level of experience and distances at the manufacturing site.

RQ 2) How can operators in complex production environments be supported in these challenges through digital and mobile ICT tools?

Operators can be supported in many ways and the specific ICT tool used to support an operator can differ vastly, even for the same challenges. An illustration of an ICT tool supporting operators is given in publication C. Positive results (such as increased trust) were gained although no increase in production could be attributed to use of the ICT tool. This example concluded that it was important for the organisation and work processes to back the use of a support tool. A short list of which information carriers operators could be supported through was presented and discussed.

RQ 3) What performance measures could be used to evaluate effects of digital and mobile ICT tools supporting operators in production environments?

Evaluation of improved or newly introduced ICT tools supporting operators can be made by using performance measures derived from different disciplines. Within this thesis, these were divided into four categories: user, activity, support tool and goal/consequence. Performance indicators were easily quantifiable and often connected to production performance and the performance of the ICT tool itself. Other performance indicators complemented by providing qualitative aspects. Exploitation of different types of measures (such as quantitative and qualitative) and measures from each of the four categories provides a broad evaluation which may capture several of the possible impacts.

A final remark: *The most suitable ICT tool is not always the most advanced one. However, in addressing the challenges operators face, considering different ways to support them and keeping a broad perspective while evaluating introduced ICT support tools will be beneficial for supporting them in their work tasks and enable them to become keys to future competitiveness and effectiveness.*





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# Publication A

*Could the use of ICT tools be the way to increase competitiveness in Swedish industry?*<sup>9</sup>

Karlsson, M., Mattsson, S., Fasth-Berglund, Å., & Stahre, J.  
12th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design, and Evaluation of Human-Machine Systems  
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# Publication B

*Managing Production Complexity by Empowering Workers: Six Cases*

Mattsson, S., **Karlsson, M.**, Fast-Berglund, Å., & Hansson, I.  
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# Publication C

*Introducing customized ICT for operators in manufacturing*

Åkerman, M., Fast-Berglund, Å., Karlsson, M., & Stahre, J.  
*Procedia CIRP*, 41, 490-495  
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# Publication D

*Perceived Production Complexity - understanding more than parts of a system*

Mattsson, S., Tarrar, M., & Fast Berglund  
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